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SECONDARY WAVES FROM NOZZLE BLAST

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OCTOBER 1984

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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Blast	Blast Computation
Rocket Launcher	Secondary Waves

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Blast signatures at the gunner's position produced by recoilless rifles and rocket launchers often exhibit a strong secondary wave following chamber blowdown. To identify its source, a series of experiments was performed using a helium-driven blast simulator. The resulting pressure traces and shadowgraphs show the wave emerging from the portion of the plume just aft of the nozzle, but leave unexplained its relationship to the plume flow field structure. This information was obtained from a numerical solution of the Euler equations using

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20. ABSTRACT (CONT'D)

Harten's Total Variation Diminishing (TVD) scheme. Based on this data, contour and surface plots of pressure were constructed which reveal quite clearly the plume wave structure and its response to the falling chamber pressure. A secondary wave emerges from the same region of the plume as it did in the experiment.

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ACKNOWLEDGEMENT

The author wishes to thank Mr. Edward Stilson for his assistance in conducting the experiments and especially for his patient labor in assembling the shadowgraphs.

INTRODUCTION

Blast signatures at the gunner's position produced by recoilless rifles and rocket launchers often exhibit a strong secondary wave following chamber blowdown. The experimental result in Figure 1, obtained with a rocket launcher, shows a wave arriving late in the firing cycle. Its intensity and duration exceed those of the primary wave.

Of course, such a wave could be due to reflection of the primary wave off a nearby surface, or it could be the result of secondary combustion aft of the weapon. It may even be a wave originating at the muzzle following shot ejection (ref 1). Previous work (refs 2-5,13) has shown that it could also be of gas dynamic origin, i.e., a result of the rapid chamber blowdown, a feature often designed into such weapons. This report describes an experimental and numerical study of the latter possibility.

THE LABORATORY EXPERIMENT

The experiment was conducted with the blast simulator described in Reference 2. Helium was used as the driver gas because it removes the possibility of secondary combustion and because its high acoustic speed simulates propellant gas behavior reasonably well (refs 3,6-9). The simulator was positioned relative to nearby surfaces such that reflected waves would not enter the test area during the period of interest.

A set of thirteen firings was made to gather pressure histories at the ninety-one gage locations shown in Figure 2. The locations formed a 5" x 5" grid. Seven gages were used during each firing. They were placed in the

References are listed at the end of this report.

horizontal plane of symmetry and on both sides of the simulator to minimize interference. Downstream of the nozzle, a pencil-type gage holder was used on the axis and for the positions just off axis. Disk type holders were used elsewhere. The complete set of pressure histories is given in the Appendix. Selected histories are presented here.

In Figure 2A, the secondary wave is seen arriving at location 31 following chamber blowdown. It has a strength of 2 psi. It becomes progressively weaker as it moves upstream, but its strength exceeds that of the primary wave at some locations. The data of Figure 2B, taken along a 45 degree angle to the simulator axis, show a similar behavior. In the exit plane, Figure 2C, the secondary wave has significant strength near the axis but becomes hard to discern at the more remote locations. This pattern is even more striking in Figure 2D, the first set of locations aft of the nozzle exit plane.

To aid in interpreting the pressure data, the set of shadowgraphs in Figure 3 was taken. Each small rectangle of film is a one-eighth reduction of a 20" x 24" negative. The first four indicate two major wave sources. One is centered at the plume head and is associated with the axial thrust of the driver gas; the other is centered near the nozzle exit and may be due to unsteadiness in the plume shear layer. Both sources produce waves which are strongest in the downstream direction. They particularly stand out in the pressure histories of Figure 2D at the outermost locations.

The first appearance of the secondary wave is in Figure 3E, taken when the chamber pressure has nearly fallen to atmospheric. It appears to be centered about a position somewhat aft of the nozzle and is traveling

upstream. The last shadowgraph shows the wave further upstream. Its strength appears to be greatest near the simulator axis and weakest off axis. This is consistent with the pressure traces and most unfortunate for the user of such weapons.

While the data clearly show that the secondary wave emerges from the plume itself, its relationship to the wave structure within the plume is not apparent. Several dozen additional shadowgraphs were taken in an effort to view this structure at late times but to no avail. It was decided that a numerical solution might be helpful in this regard.

THE COMPUTER EXPERIMENT

A computer simulation of the laboratory experiment was not attempted since its large size at the time of secondary wave formation would require unreasonable computer storage to produce the desired detail within the plume. Instead, the problem sketched in Figure 4A was considered. Helium flows from a reservoir, through a variable area orifice, into a chamber fitted with a converging nozzle; the nozzle discharges to the stagnant atmosphere occupying the half-plane to the right of the nozzle exit. Conditions in the reservoir are held constant at 140 times atmospheric pressure and at atmospheric temperature. The chamber is initially filled with air so a mixture of the two gases is vented at early times. The flow up to the nozzle exit is treated as quasi-steady.

Downstream, the transient, axisymmetric, inviscid equations of motion are solved using Harten's Total Variation Diminishing (TVD) scheme for solving systems of hyperbolic equations (refs 10,11). It is a second-order, shock-

capturing, non-oscillatory method. A description of how the method is applied to the present problem is given in Reference 12.

The variable area orifice supplying the chamber opens and closes with a sinusoidal temporal variation. The chamber state is a function of the nozzle exit conditions which, for subsonic outflow, also depend on the flow downstream. Pressure and density histories are shown in Figure 4B.

The flow structure shortly after peak chamber pressure is shown in Figure 5A. Equally spaced contours of pressure are plotted. Contours were omitted near the nozzle exit because the strong expansion would render the region black (see the pressure surface plot at the top of the figur e Mach disk and the oblique and intercepting shocks defining the shock ottle are easily identified. The heavier solid line represents the plume boun . It is actually a contour plot of the mole fraction of the air (ref 12); five contour levels equally spaced over the range 0.49 to 0.51 are shown.

Within the plume, the velocity vectors help to delineate the contact surface separating the freshly discharged gas, which moves at supersonic speed, from gas released earlier and which now forms a subsonic layer surrounding the shock bottle. The vectors also show the vortex region at the plume head.

The surface plot in Figure 5A shows that the pressure level is about two atmospheres downstream of the shock bottle. This region is supported on the upstream side by the momentum of the supersonic gas flow and on the downstream side by the resistance of the stagnant atmosphere. As the chamber pressure continues to fall, the high pressure region spreads out in both the upstream direction, because the gas stream has a decreasing amount of momentum to

support it, and in the downstream direction as the primary shock engulfs more of the atmosphere. In Figure 5C, the upstream progress of the pressure wave can be seen as it passes through the lower half of the vortex and distorts the contour lines. Note that the flow behind the Mach disk has actually been reversed temporarily.

In Figures 5D and 5E, the pressure wave is seen as it passes through the plume boundary. The pressure surface plots in these two figures show only the area covered by the contour plots in order to emphasize the secondary wave. Also, the surface is viewed from the solid boundary rather than along the axis as before.

The passage of the pressure wave through the vortex is impeded by the counterclockwise motion of the gas in that region. Just outside the shock bottle, however, the gas has a low velocity and is actually turned upstream by the shock. The figures give the appearance of a near spherical pressure wave traveling upstream, but one which also must diffract around the vortex and thus weaken in the radial direction. The same characteristic was observed in the laboratory experiment.

CONCLUSION

It would appear that a necessary requirement for the emergence of a secondary wave is a chamber blowdown sufficiently rapid to allow it to squeeze through between the shock bottle and the vortex. A more gradual blowdown would provide upstream support while the high pressure region decayed along with the progressively weakening primary shock. Unfortunately, this would also imply longer projectile travel distances. The computer model provides a

way of estimating the necessary trade-off.

The grid used in this problem was 150 cells in the axial direction and 120 cells in the radial direction. The plume, where much of the action takes place, occupied less than half this space. Only five cells were used across the nozzle exit plane. Nevertheless, Harten's scheme provided sufficient flow field definition and has much to recommend its use for problems of this type.

REFERENCES

1. Clayden, W. A. and Hillman, A., "Some Recent Work on Noise From Shoulder-Launched Recoilless Weapons," RARDE paper presented to TTCP W2 Workshop, 1978.

2. Carofano, G. C., "Laboratory Simulation of Recoilless Rifle Backblast," Proceedings of the Third International Symposium on Ballistics, 23-25 March 1977, Karlsruhe, Germany, paper C1. (This paper may also be found in the Appendix of Reference 3).

3. Carofano, G. C., "A Comparison of Blast Data From a 105 mm Recoilless Rifle and a Laboratory Simulator," ARLCB-TR-78020, USA ARRADCOM, Benet Weapons Laboratory, Watervliet, NY, November 1978.

4. Groetzinger III, W. H., Ed., "Evaluation of In-Tube-Burning Rockets For Advanced LAW (U)," Technical Report S-244, Rohm & Hass Co., Redstone Research Laboratory, Redstone Arsenal, Alabama, December 1969 (C).

5. Groetzinger III, W. H., Ed., "Evaluation of In-Tube Burning Rockets For Advanced LAW (U)," Technical Report S-208, Rohm & Haas Co., Redstone Research Laboratory, Redstone Arsenal, Alabama, April 1969 (C).

6. Grimshaw, J. F. and Pennelegion, L., "The Simulation of Infantry Weapon Blast Using a Compressed Gas Source," Sixth International Symposium on Military Applications of Blast Simulators, Cahors, France, June 1979.

7. Grimshaw, J. F. and Pennelegion, L., "A Parametric Study of Weak Blast Waves From Conical Nozzles Driven by Compressed Gases," Royal Military College of Science Report No. 78004, Shrivenham, September 1972.

8. Ponting, R., "Some Recent RMCS Work in the Field of Intermediate Ballistics," Technical Proceedings of the Blast Overpressure Workshop, Dover, New Jersey, 25-26 May 1982.

9. Ponting, R. and Pennelegion, L., "The Simulation of Weapon Blast Using a Burning Propellant Source," Royal Military College of Science, Shrivenham, September 1981.

10. Harten, A., "High Resolution Schemes For Hyperbolic Conservation Laws," J. Computational Physics, Vol. 49, No. 3, March 1983, pp. 357-393.

11. Yee, H. C., Warming, R. F., and Harten, A., "On the Application and Extension of Harten's High-Resolution Scheme," NASA TM 84256, Ames Research Center, Moffett Field, CA, June 1982.

12. Carofano, G. C., "Blast Computation Using Harten's Total Variation Diminishing Scheme," ARDC Technical Report ARLCB-TR-84029, Benet Weapons Laboratory, Watervliet, NY, October 1984.

13. Arszman, J. H., "Impulsive Noise of Propulsion Systems -- Sources, Analysis, Control," U.S. Army Missile Command, Technical Report RK-82-7, Redstone Arsenal, Alabama, July 1983.

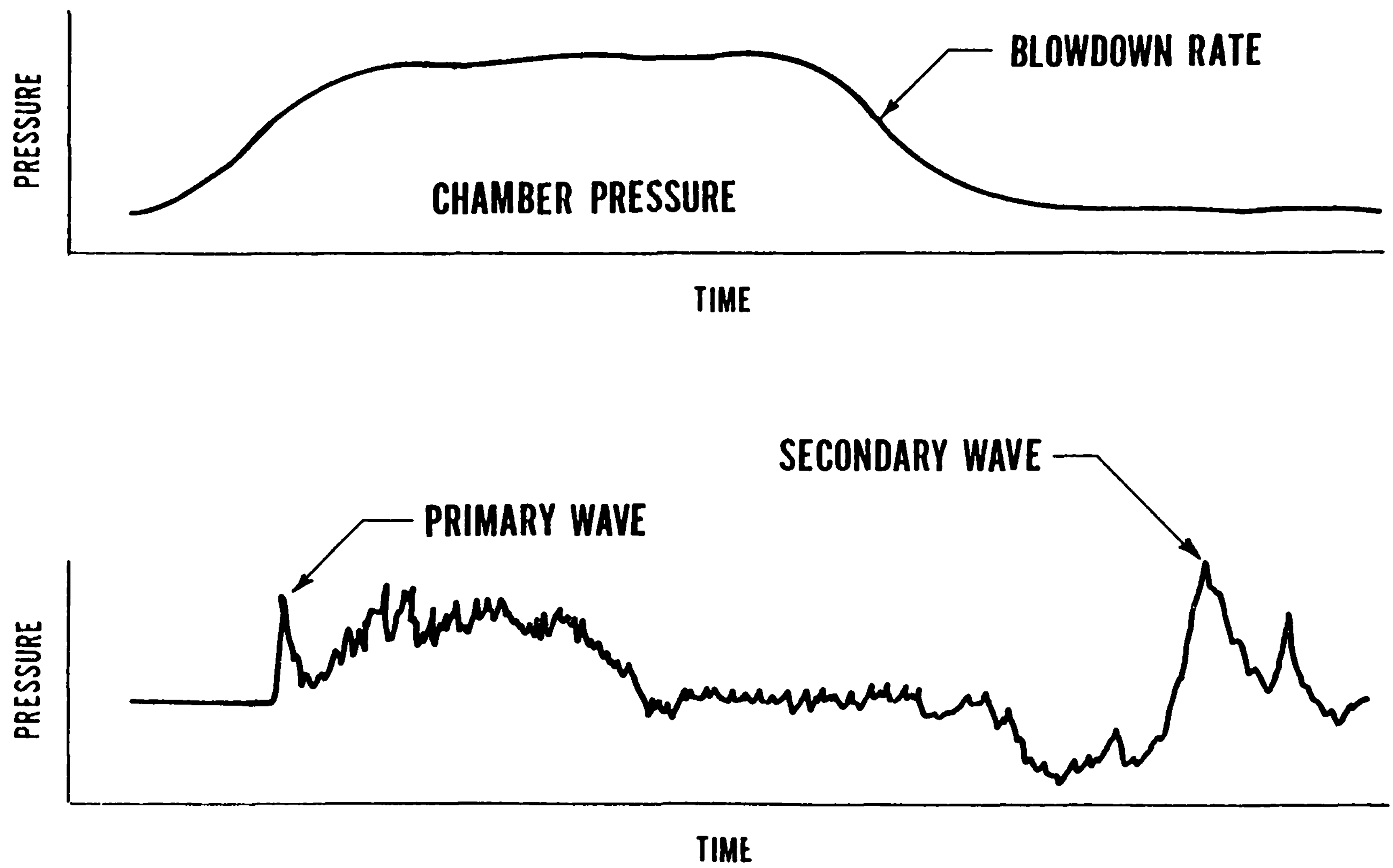


Figure 1. Blast Signature From a Rocket Launcher.

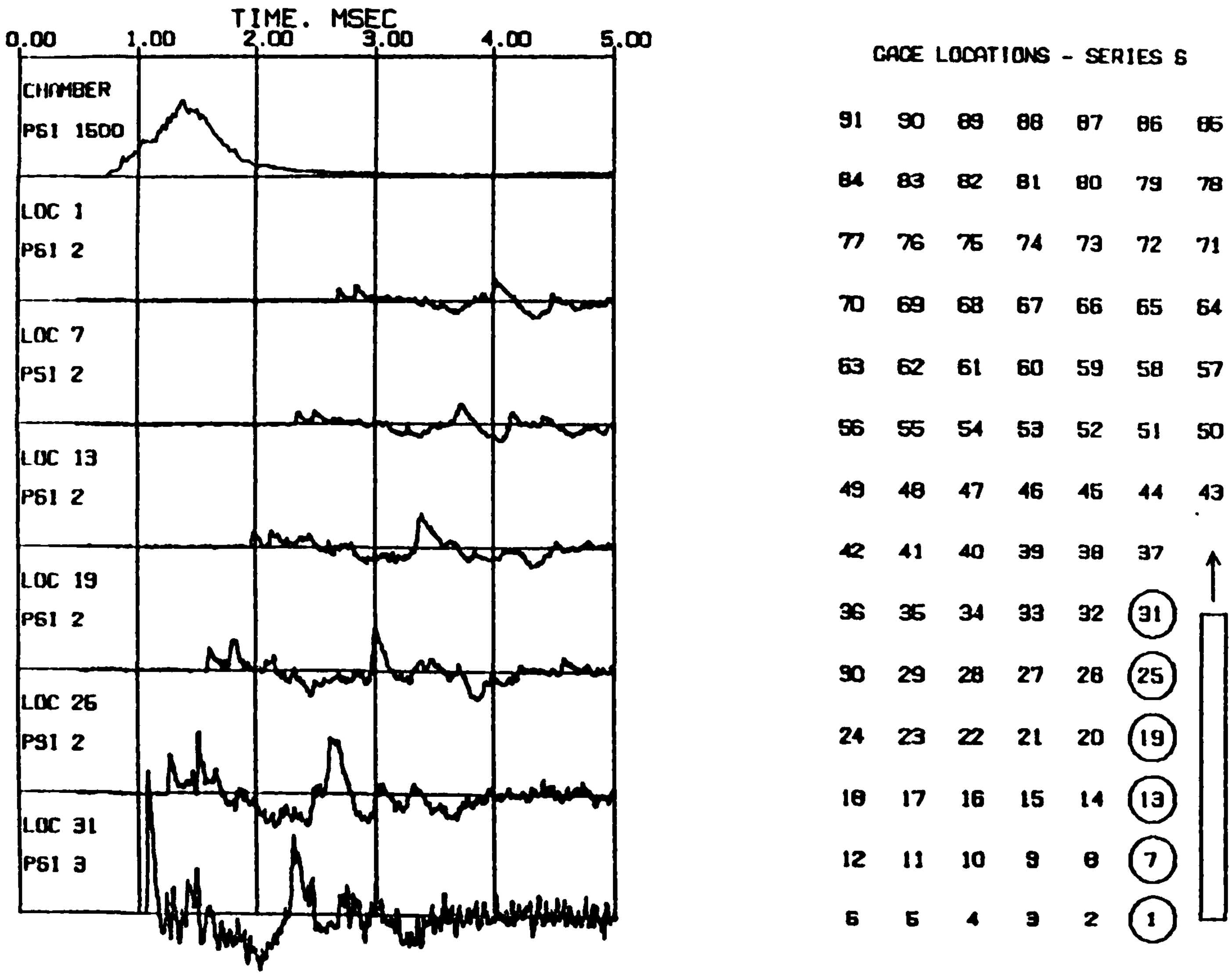


Figure 2A. Experimental Pressure Traces.

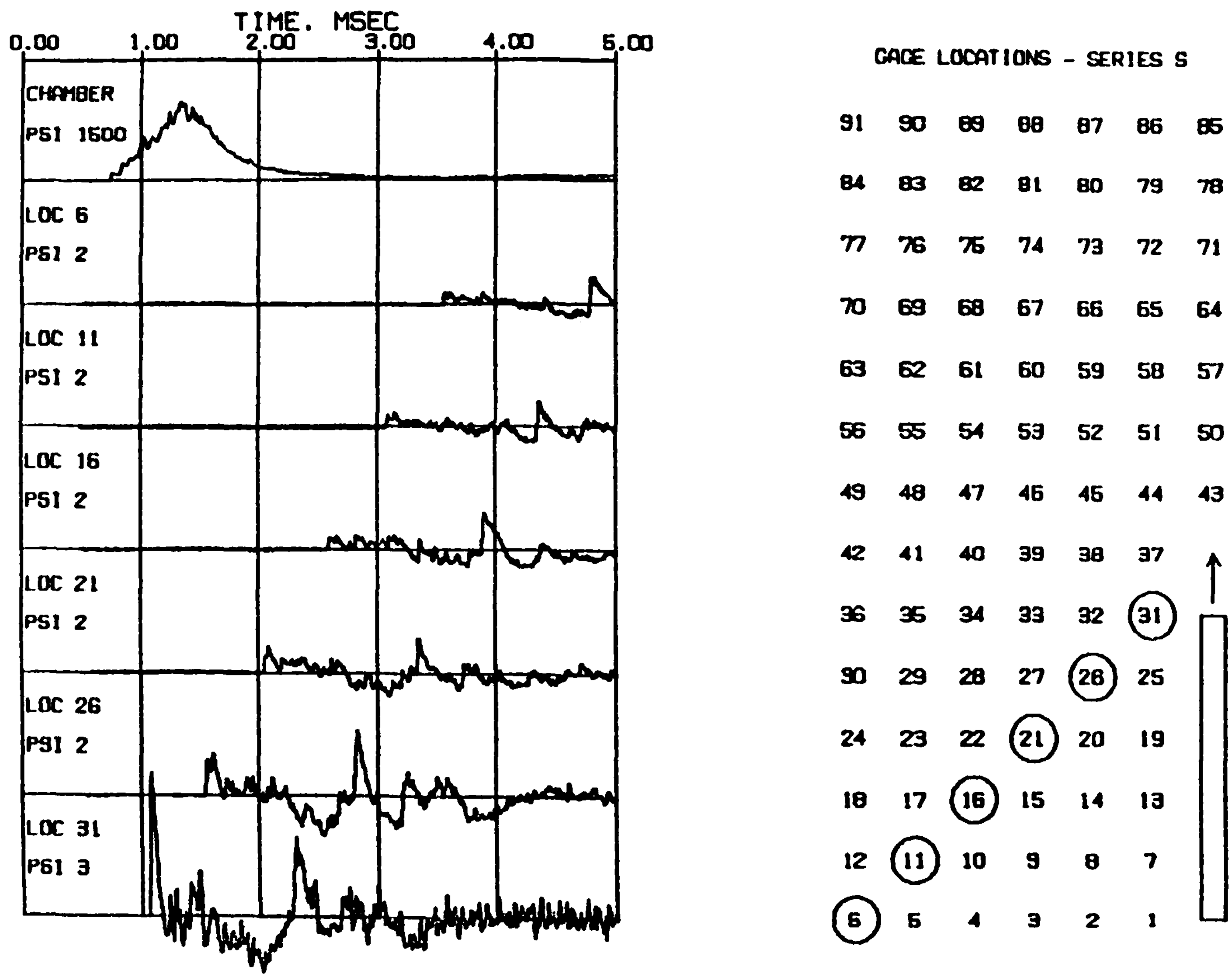


Figure 2B. Experimental Pressure Traces.

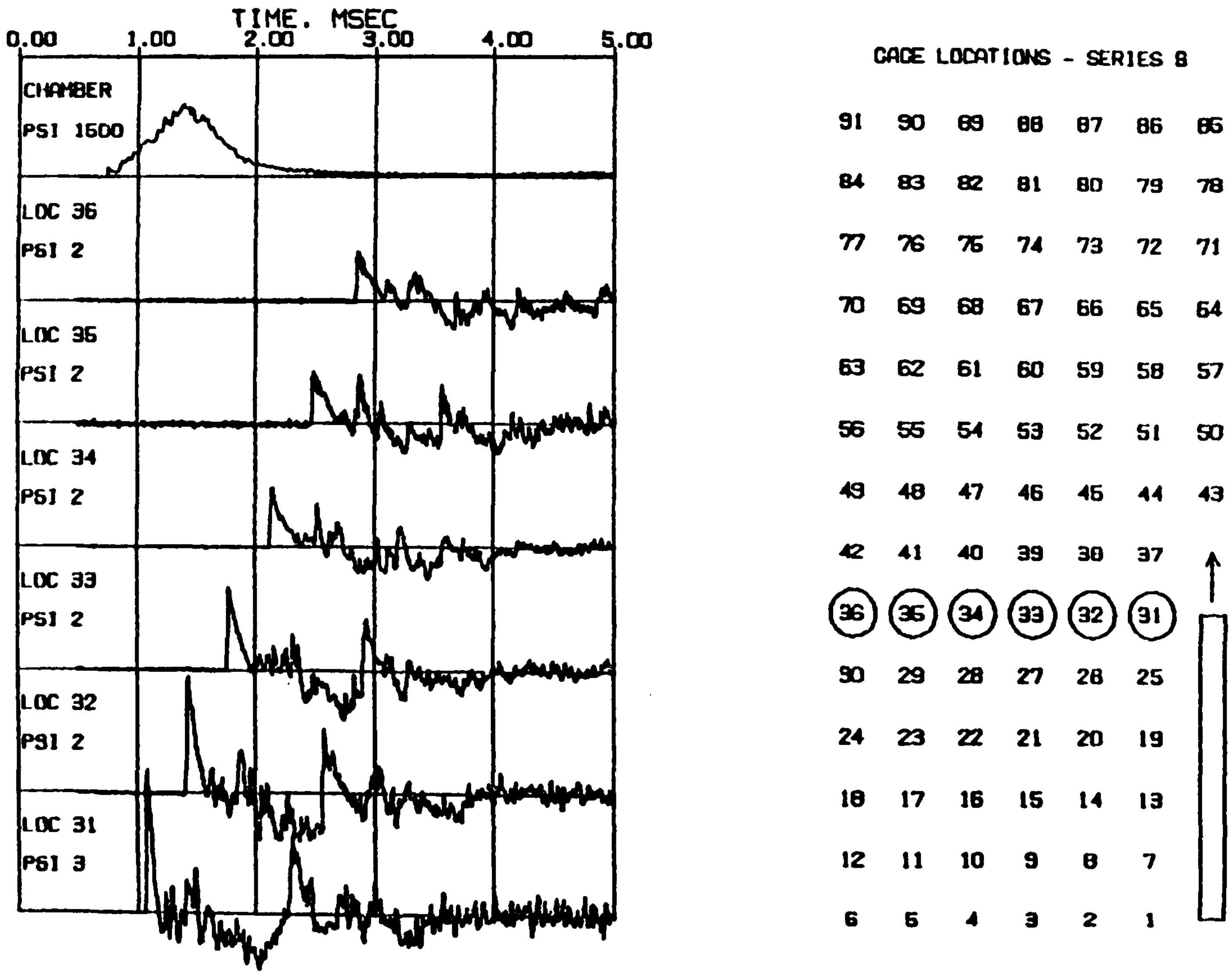


Figure 2C. Experimental Pressure Traces.

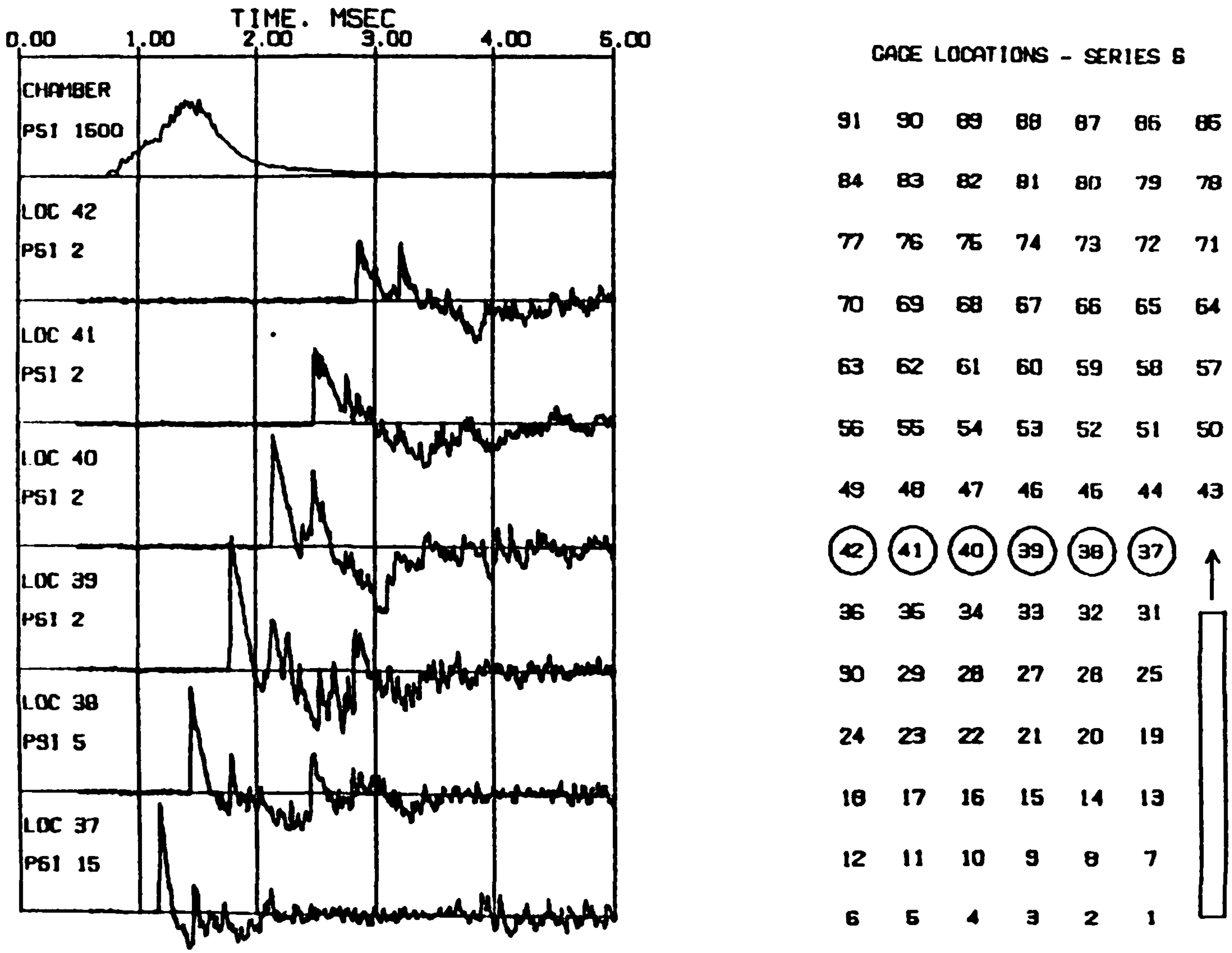


Figure 2D. Experimental Pressure Traces.

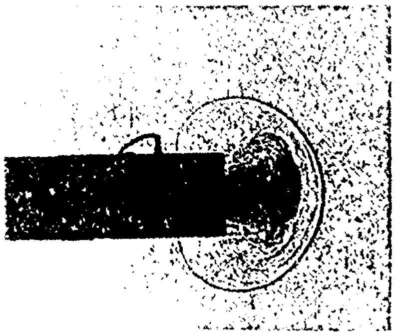


Figure 3A. T = 1.06 msec.

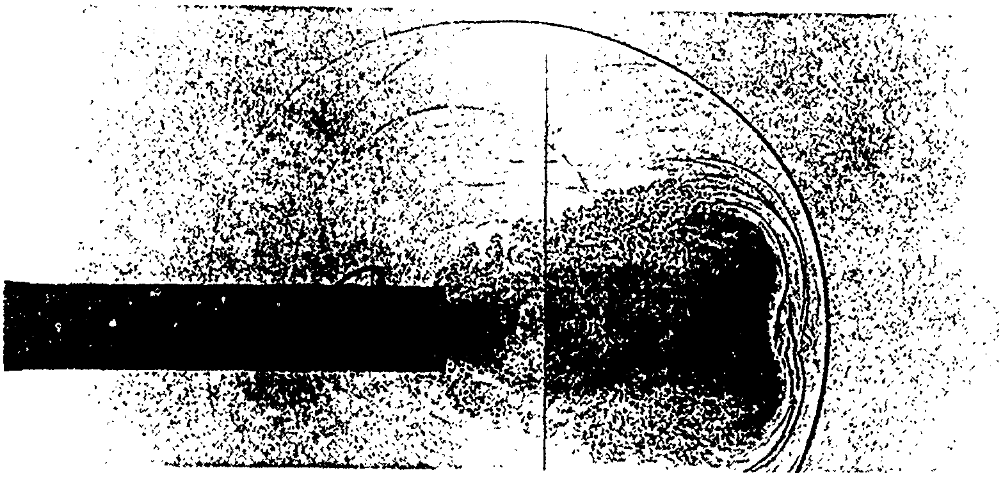


Figure 3B. T = 1.42 msec.

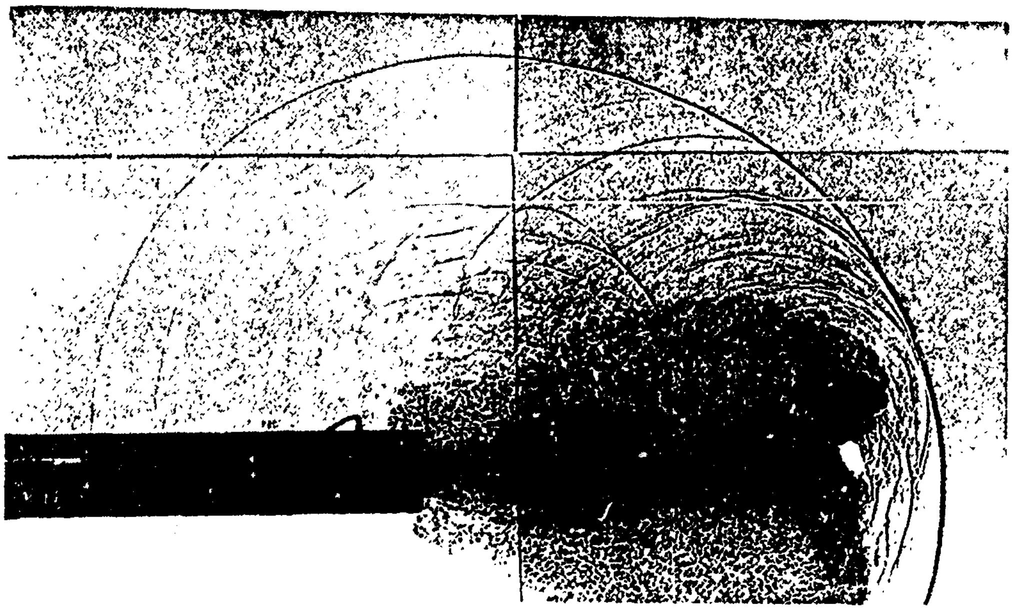


Figure 3C. T = 1.68 msec.

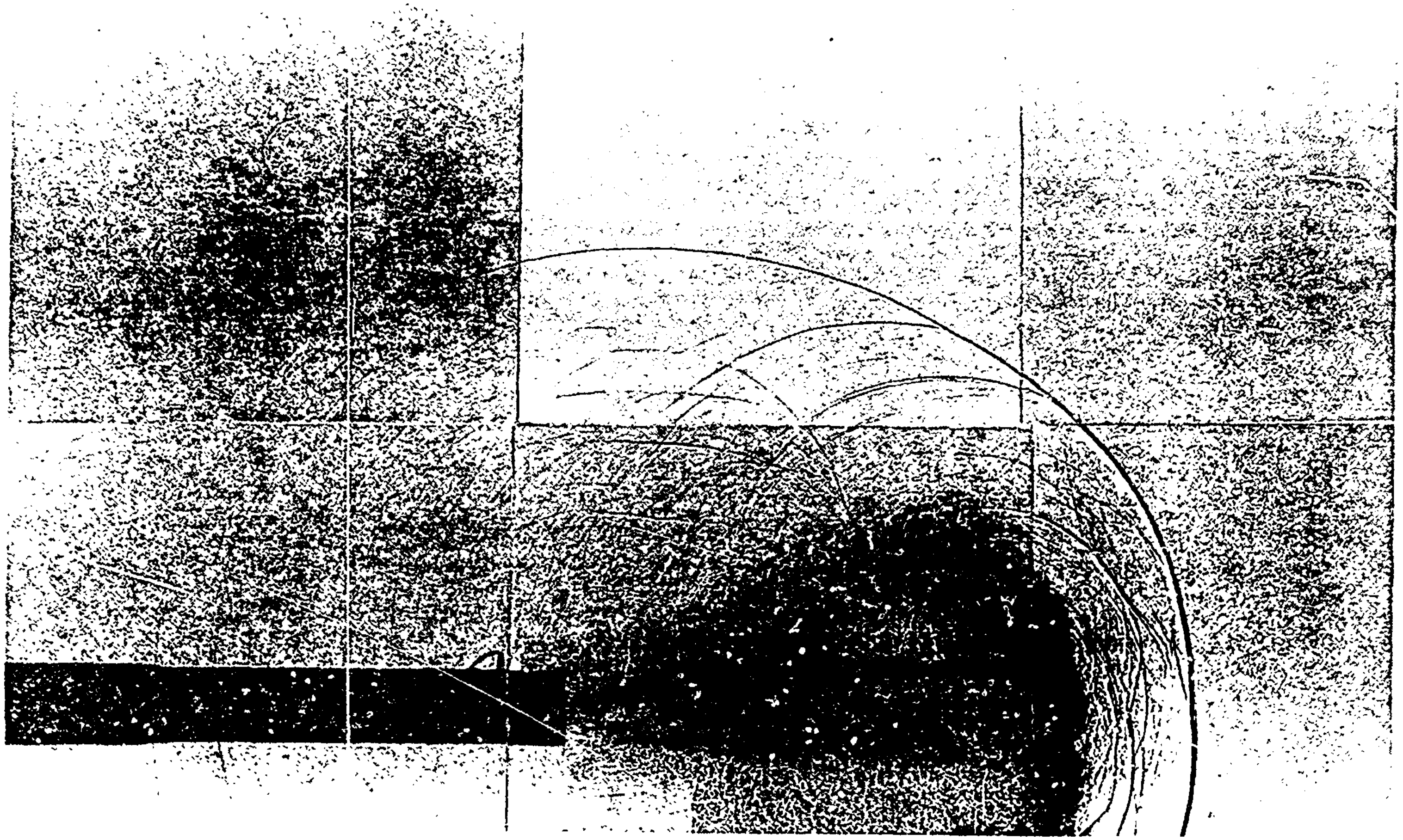


Figure 3D. T = 1.91 msec.

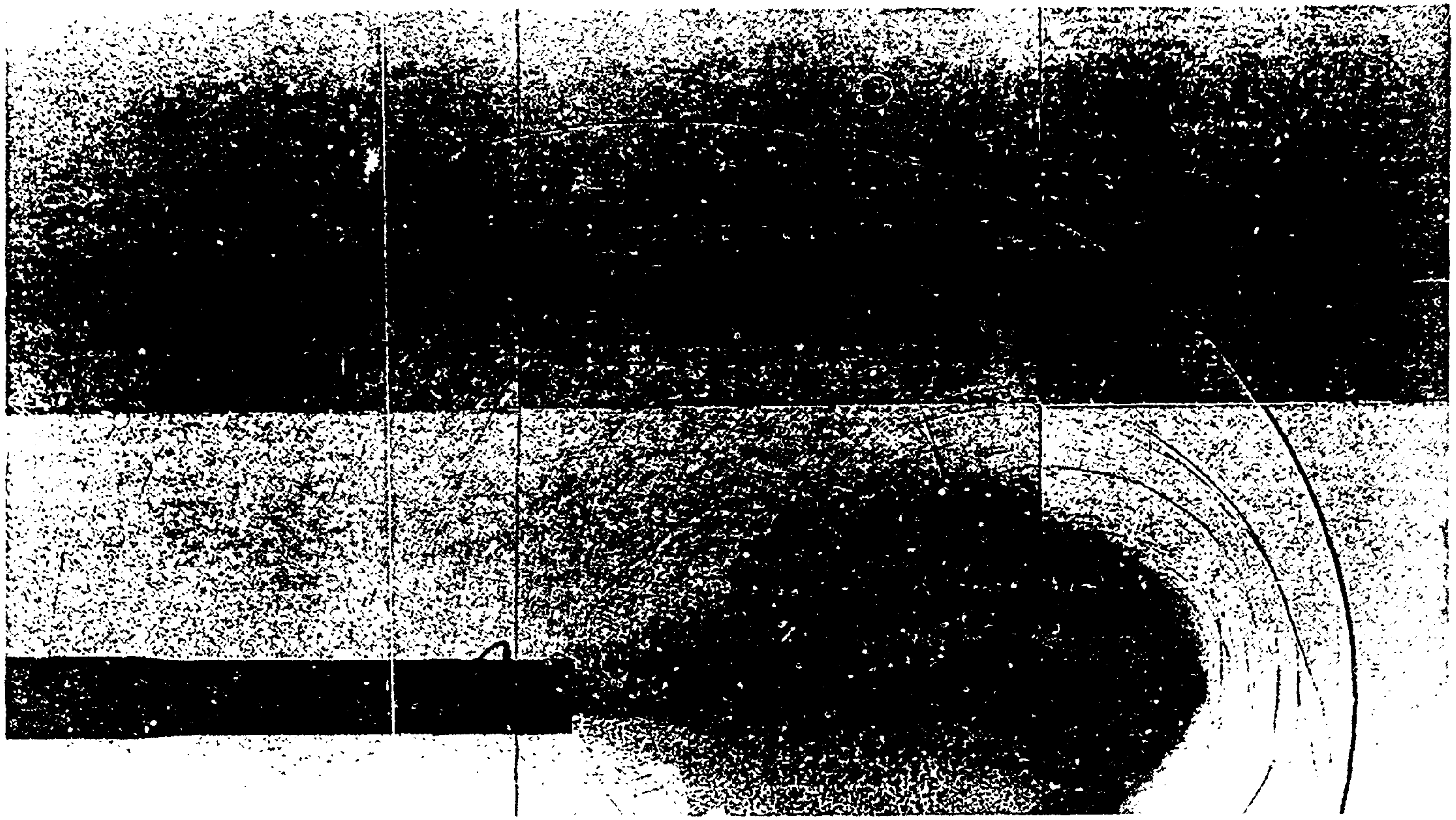


Figure 3E. T = 2.19 msec.

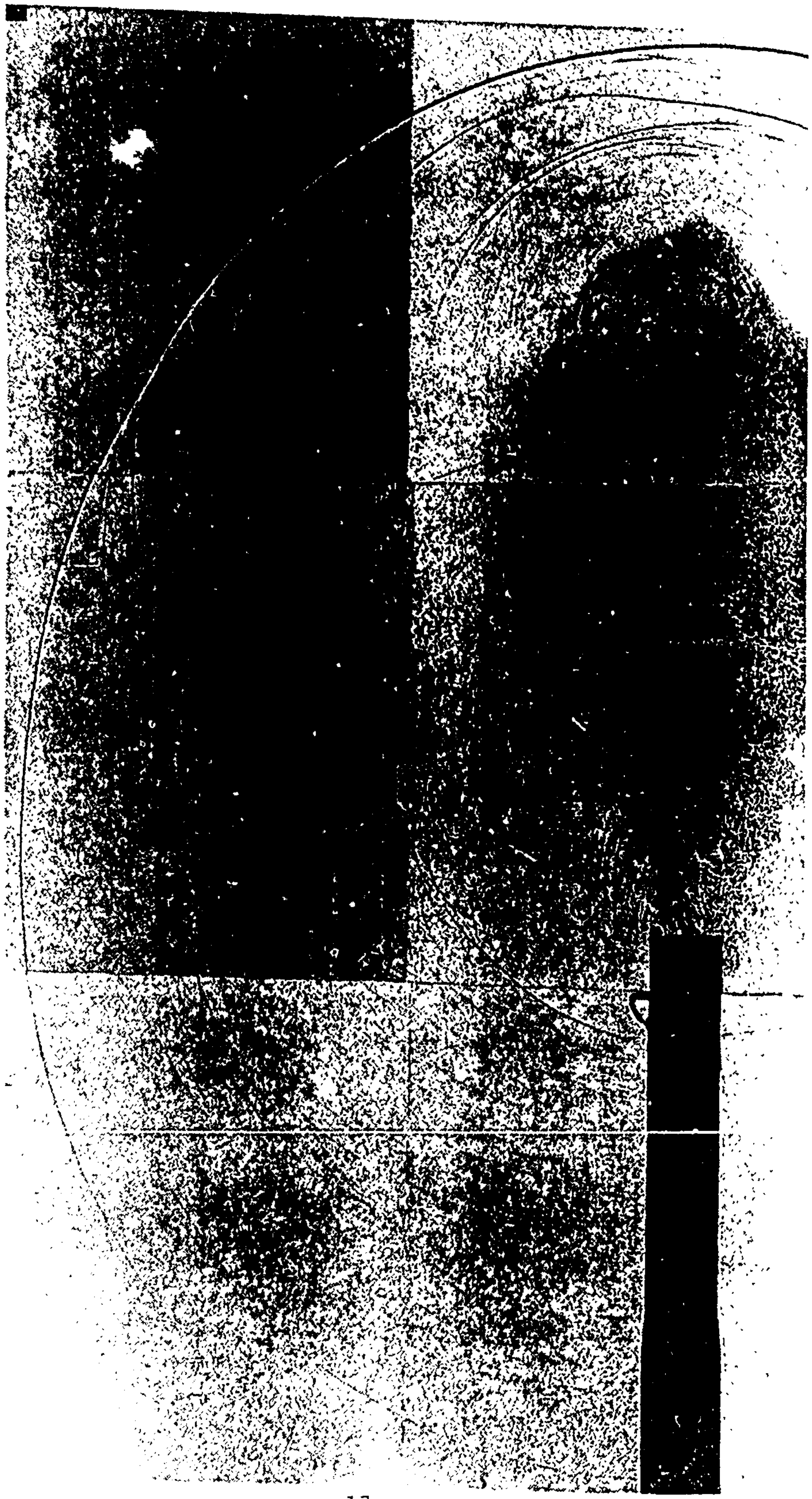


Figure 3F. T = 2.51 msec.

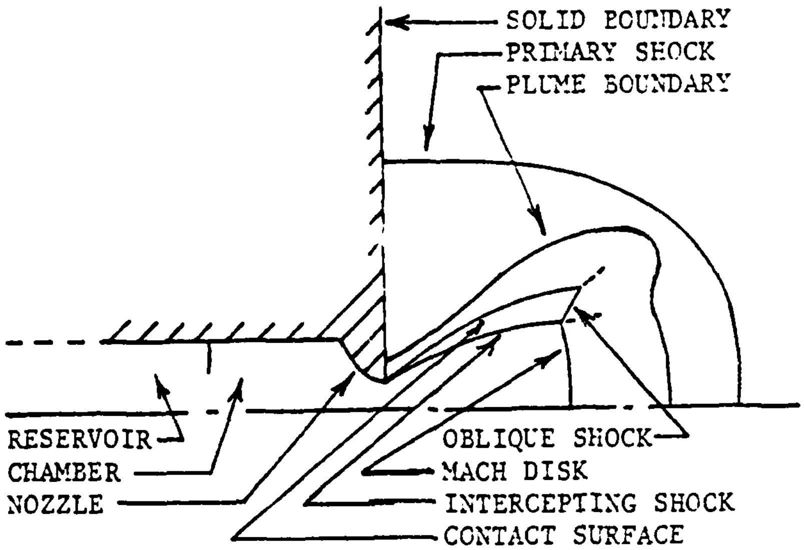


Figure 4A. Problem Sketch.

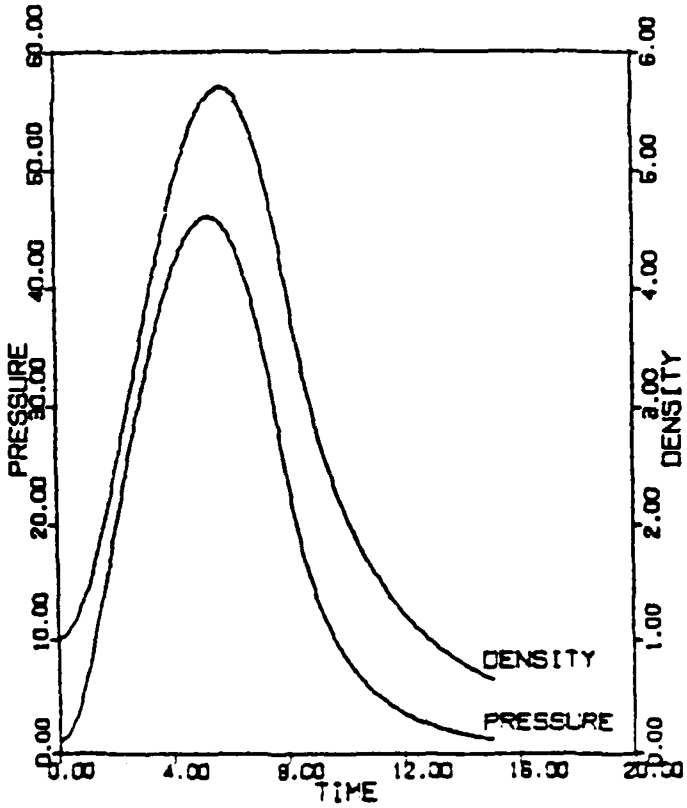
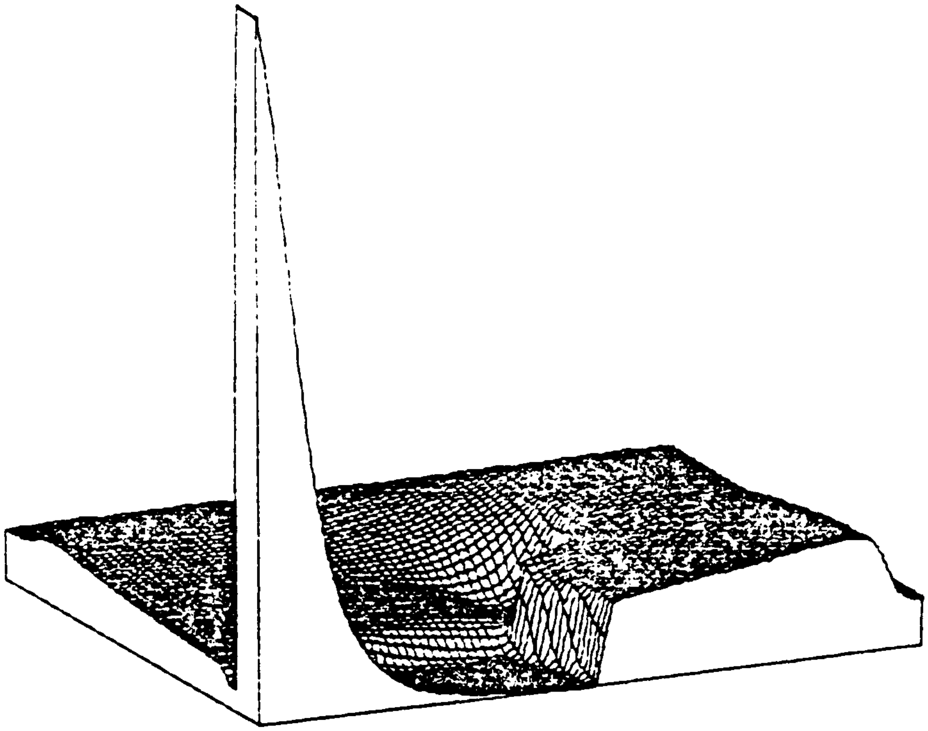


Figure 4B. Chamber Histories.



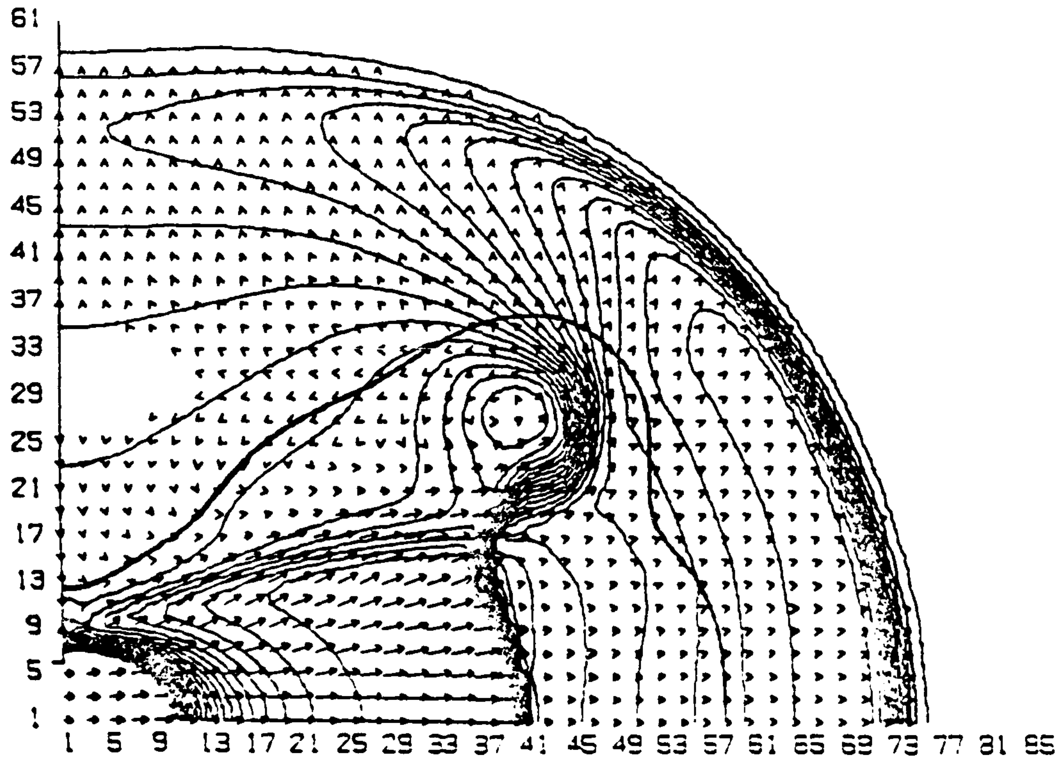
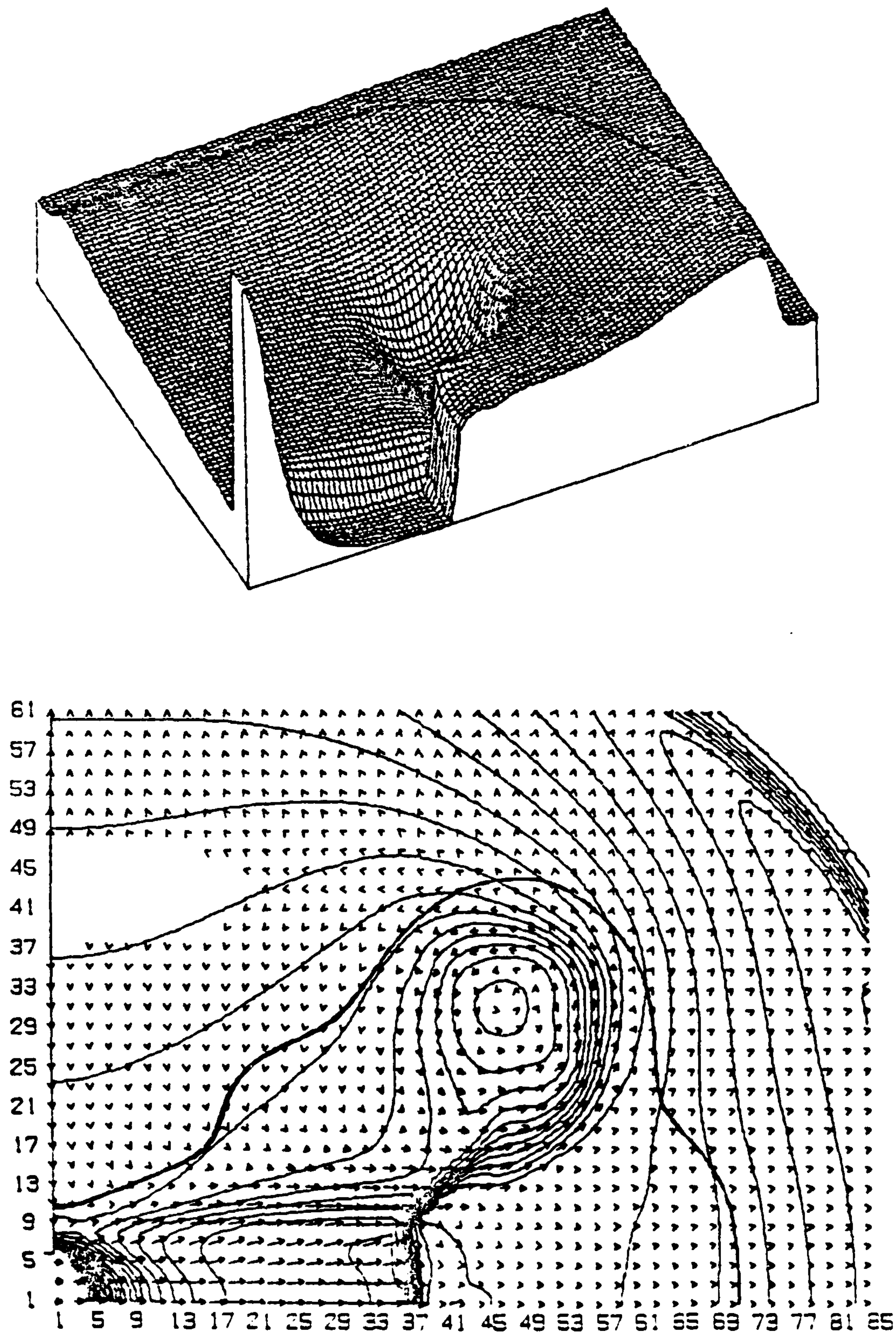


Figure 5A. Pressure Plots at t = 7.675.



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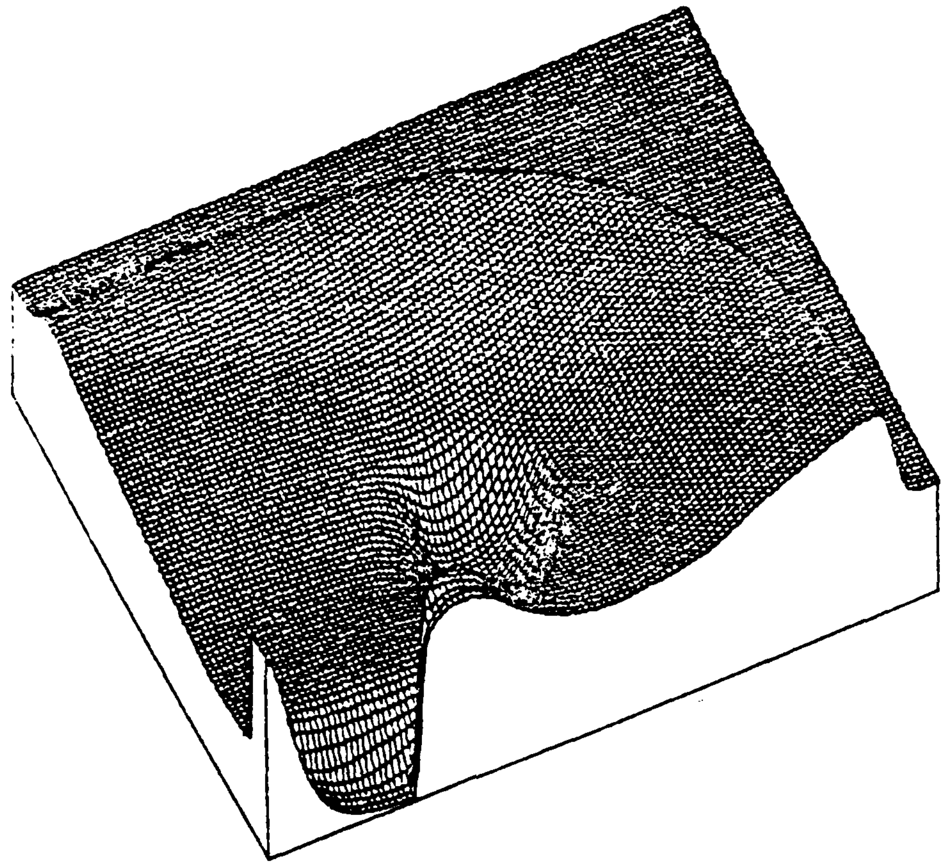


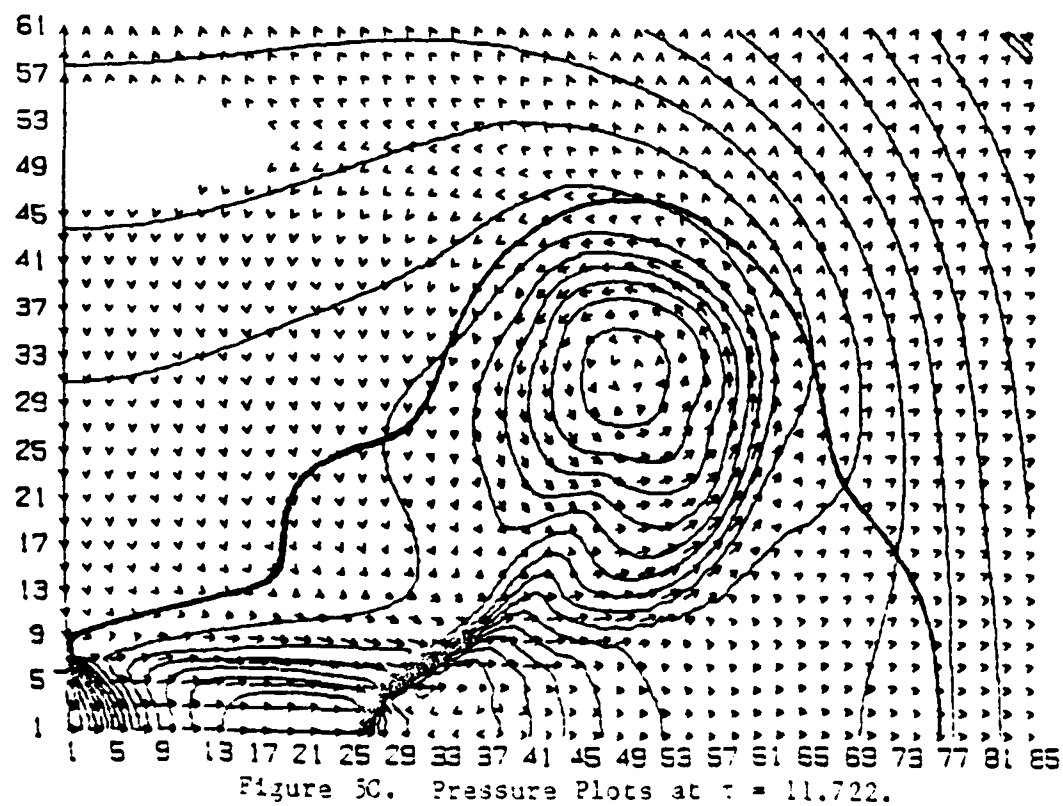
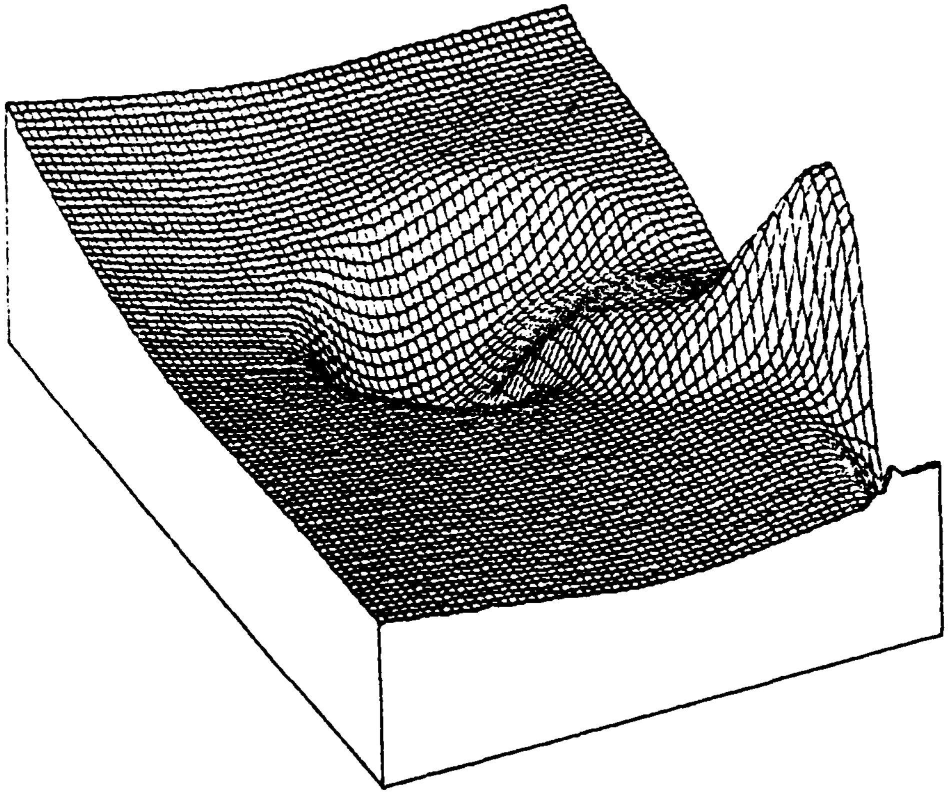


Figure 5C. Pressure Plots at τ = 11.722.



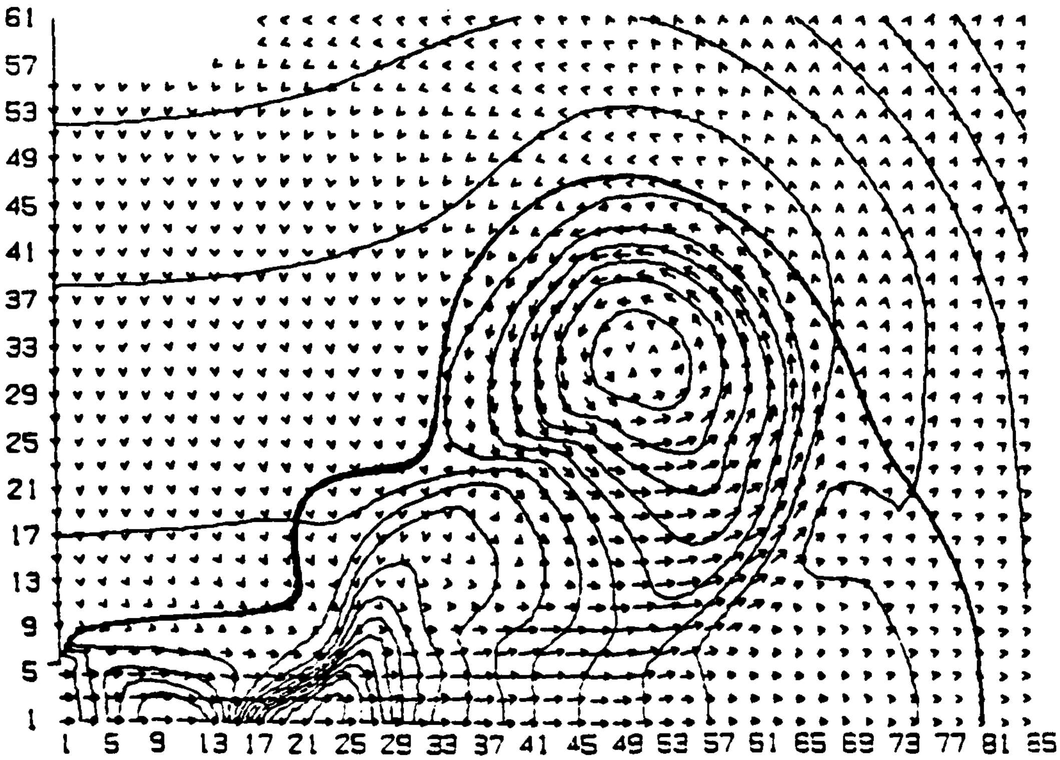
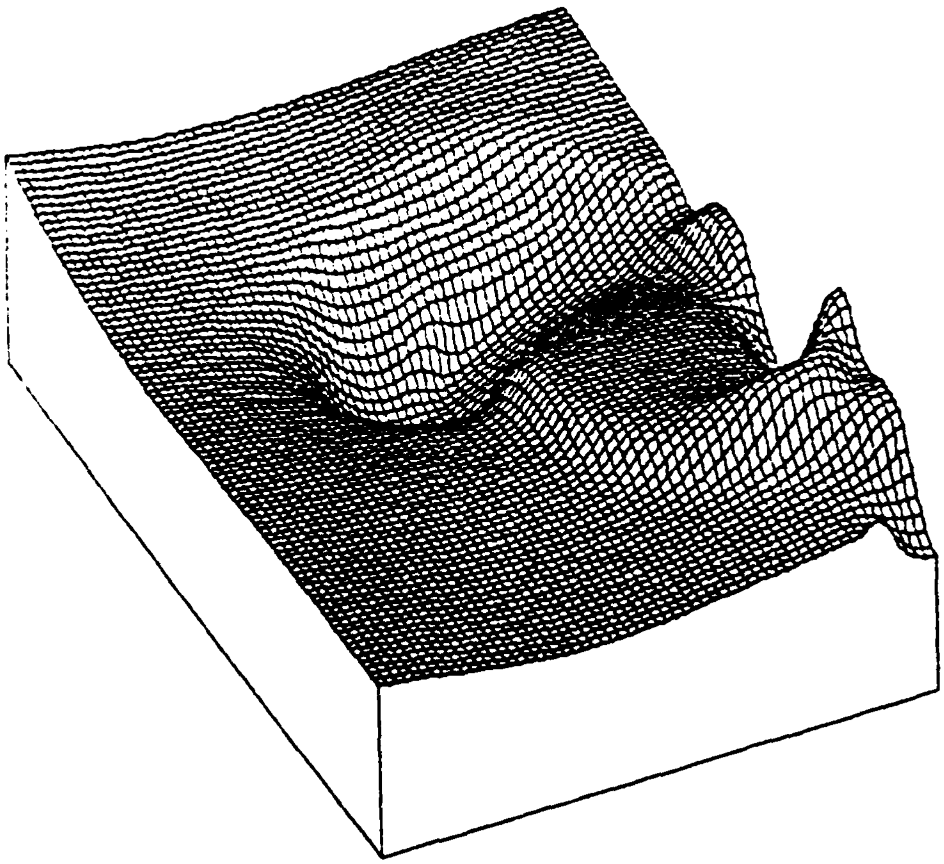


Figure 5D. Pressure Plots at τ = 13.357.



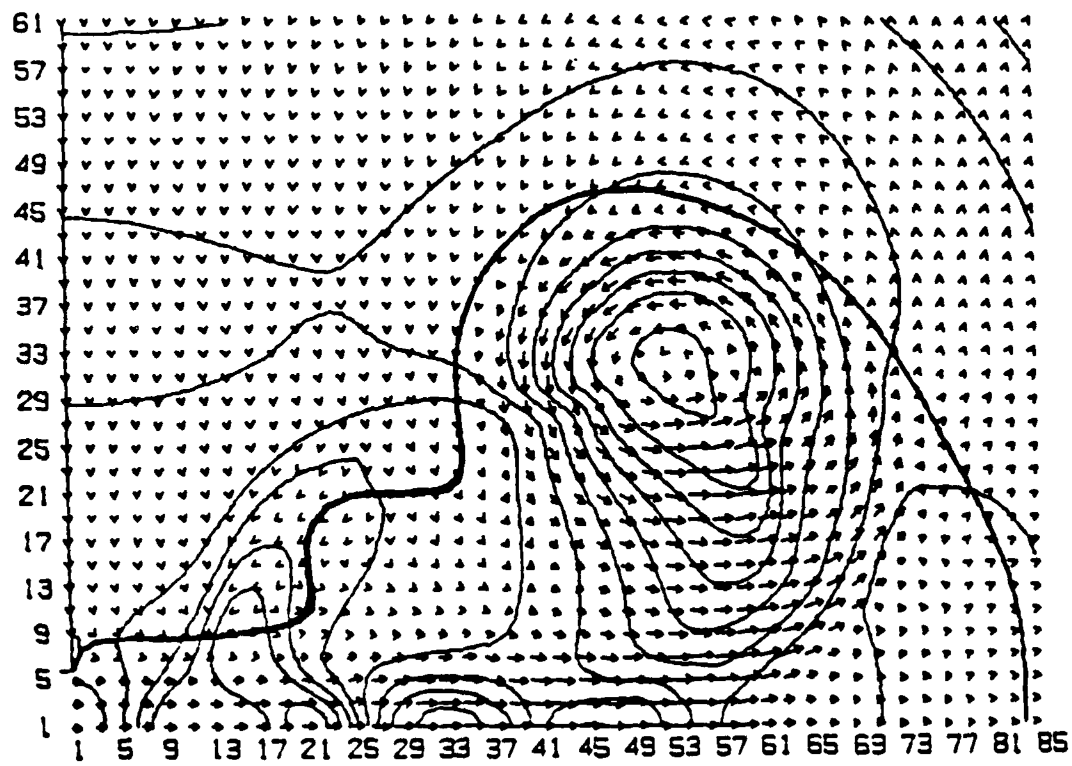
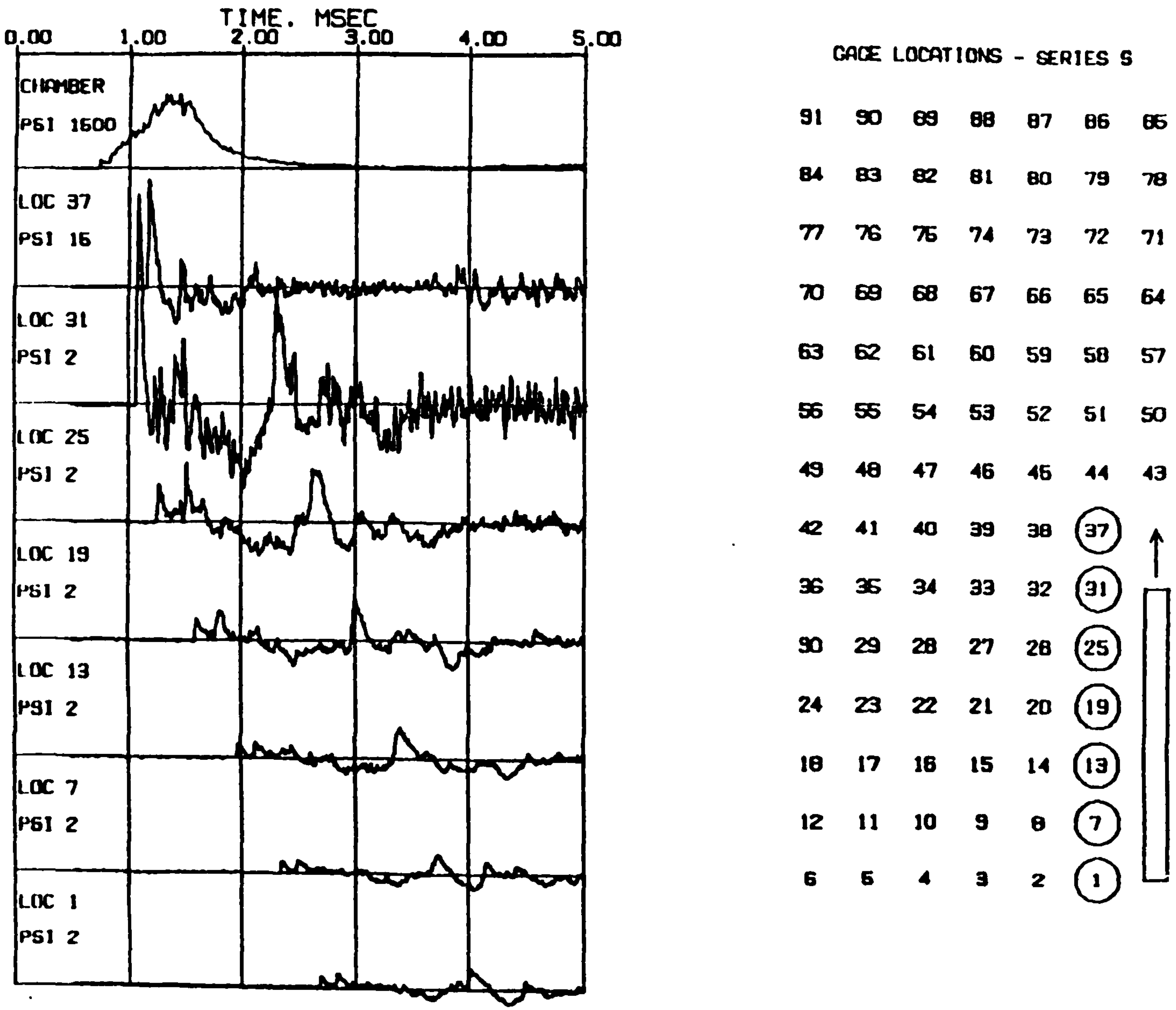


Figure 5E. Pressure Plots at τ = 15.046.

APPENDIX

This appendix contains the complete set of pressure histories taken during the experiments.



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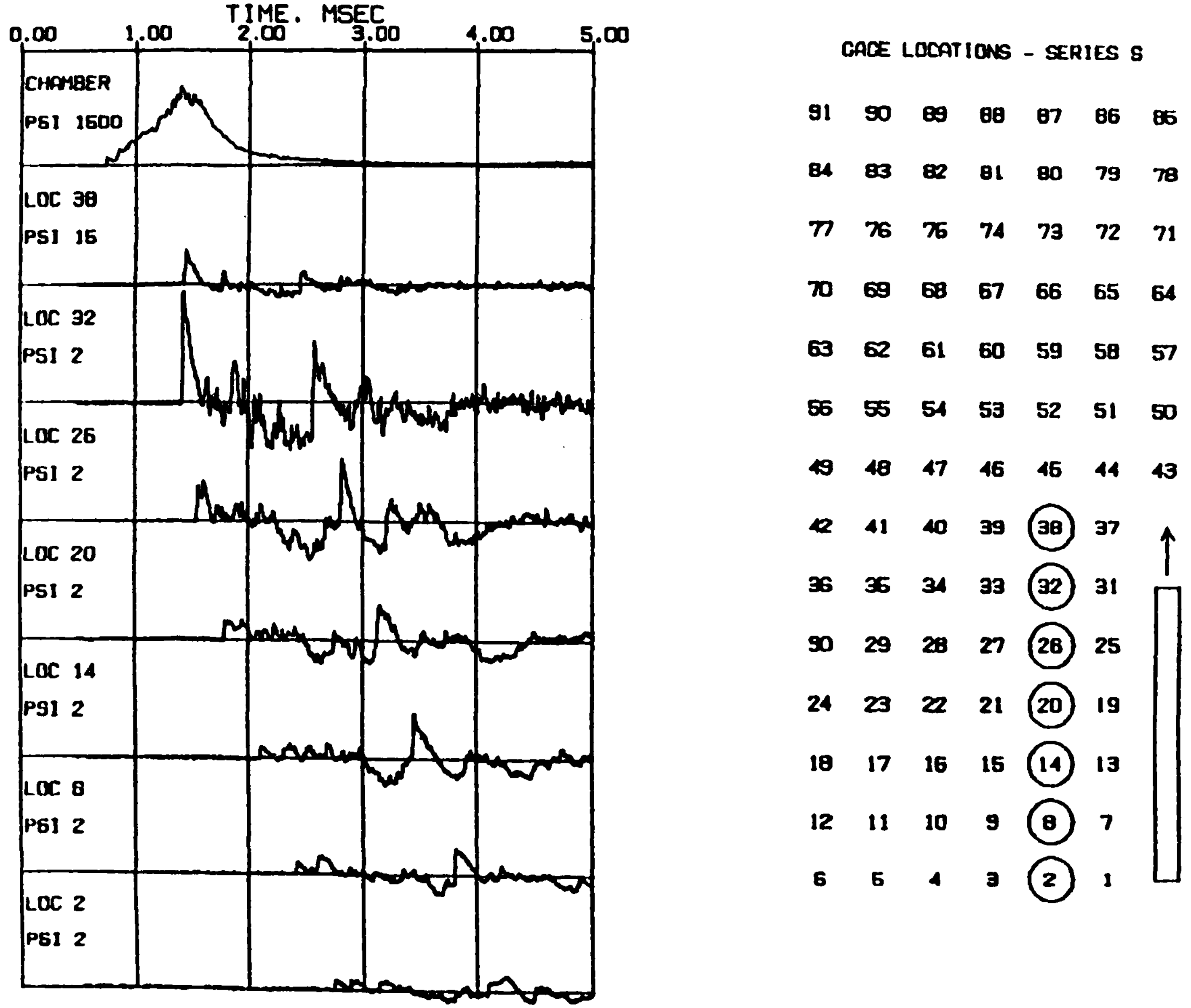

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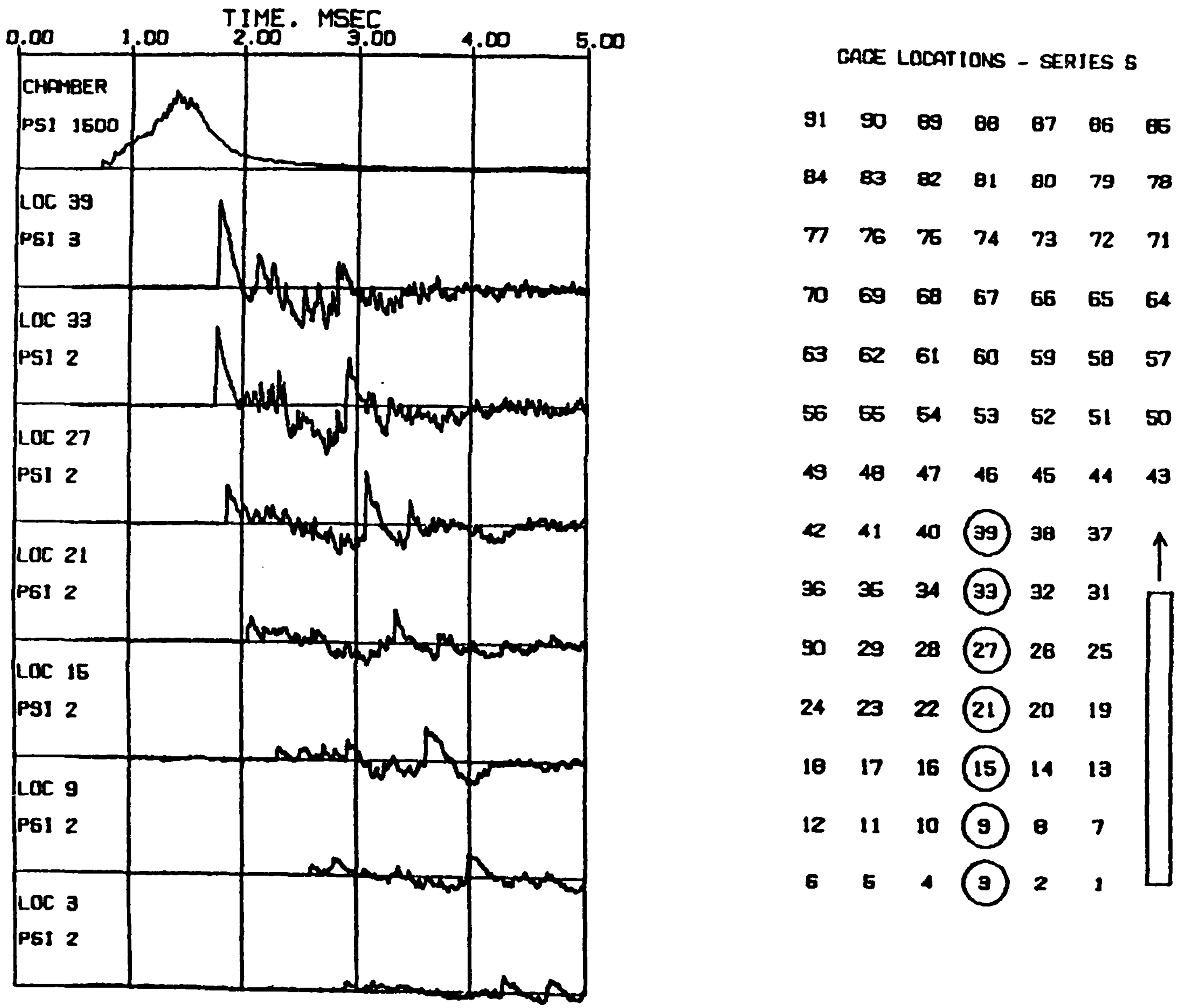

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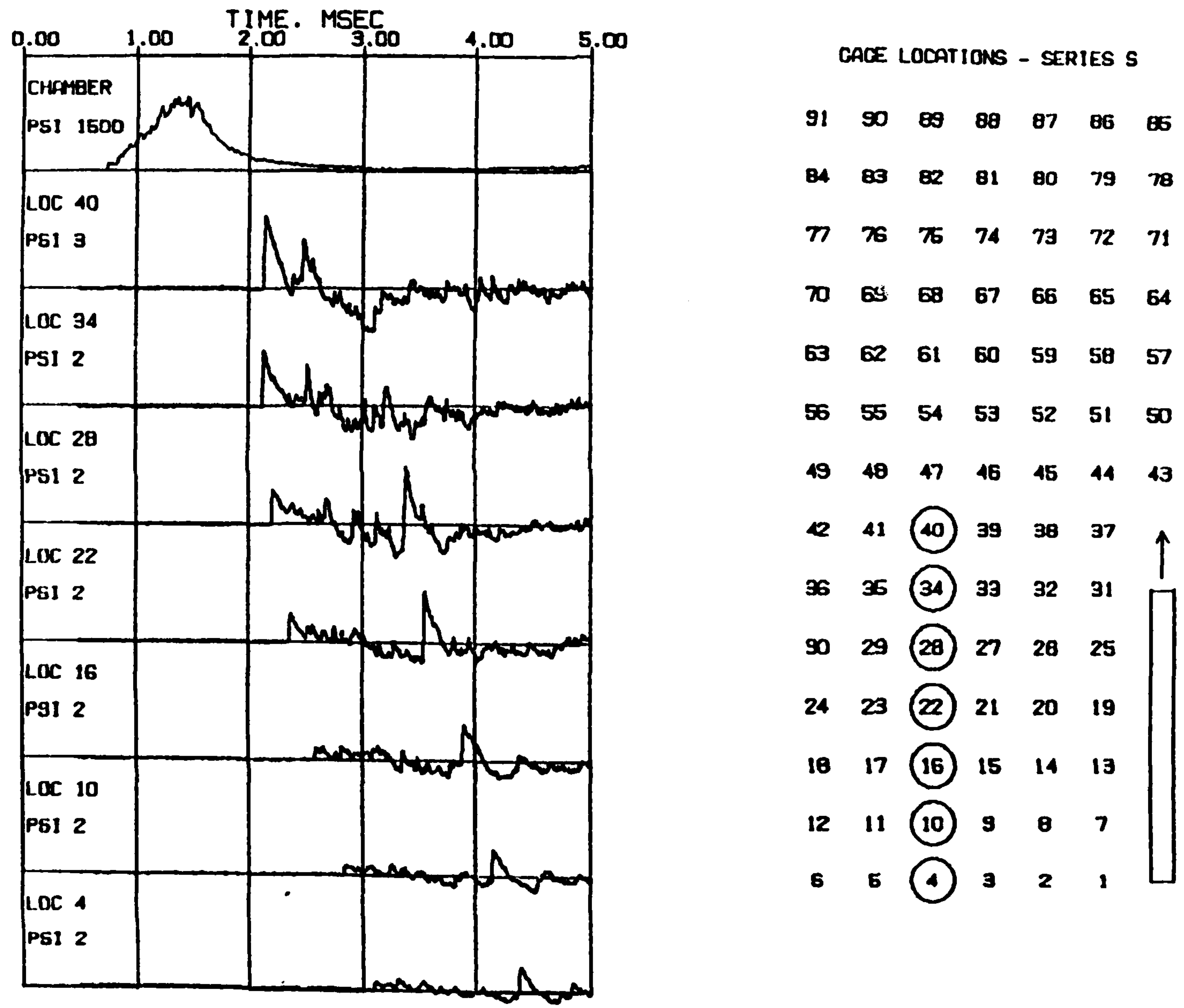

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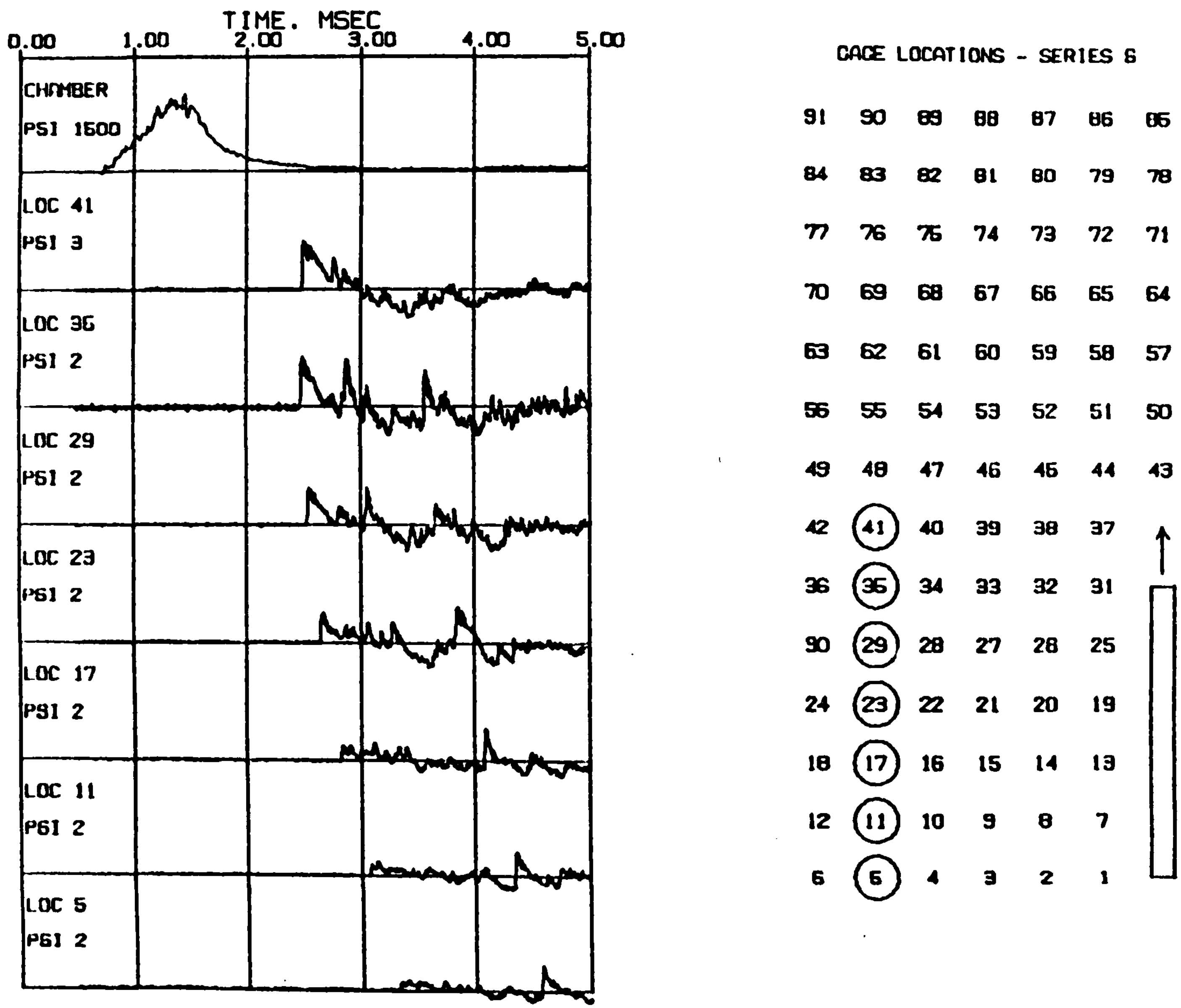

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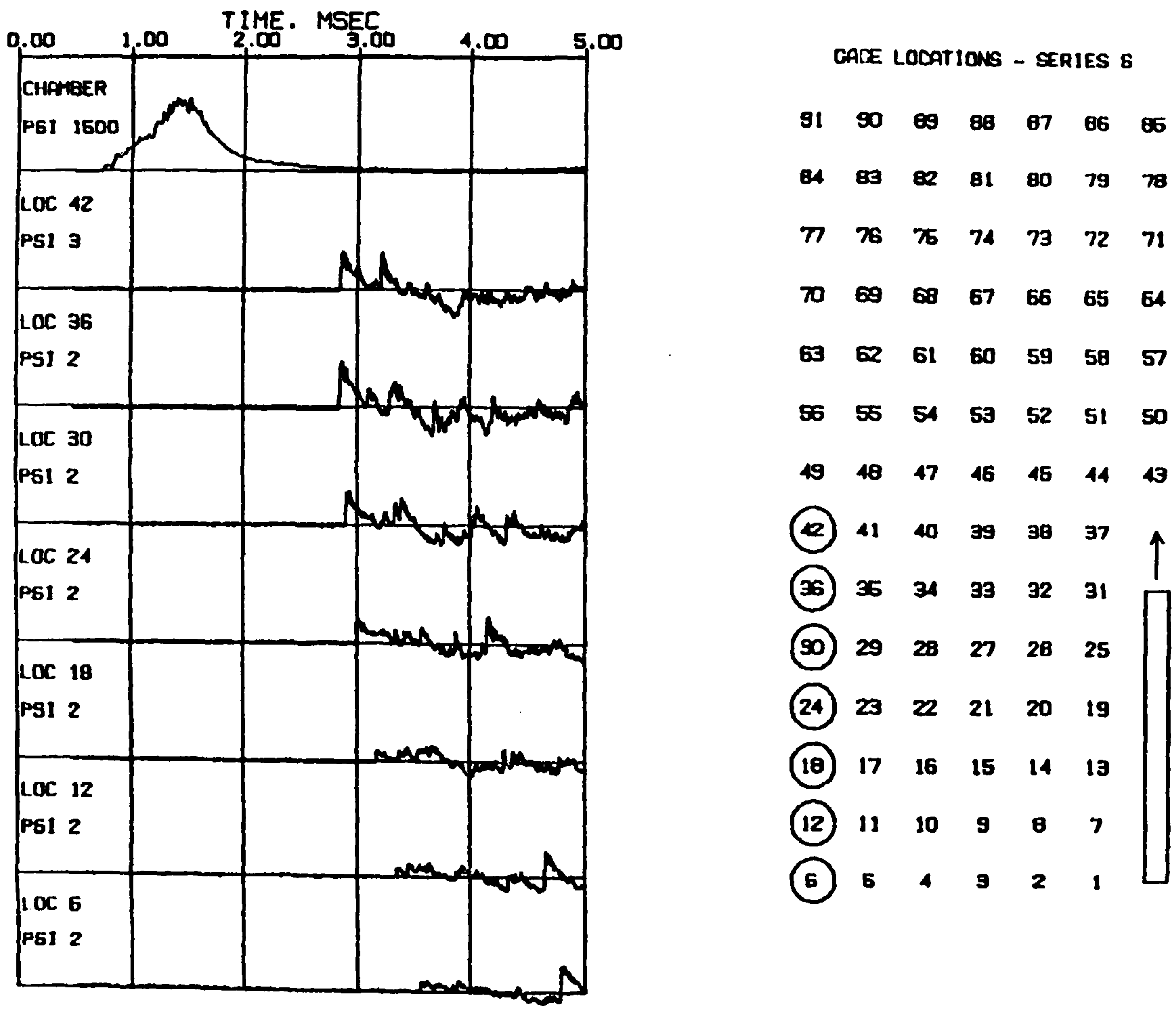

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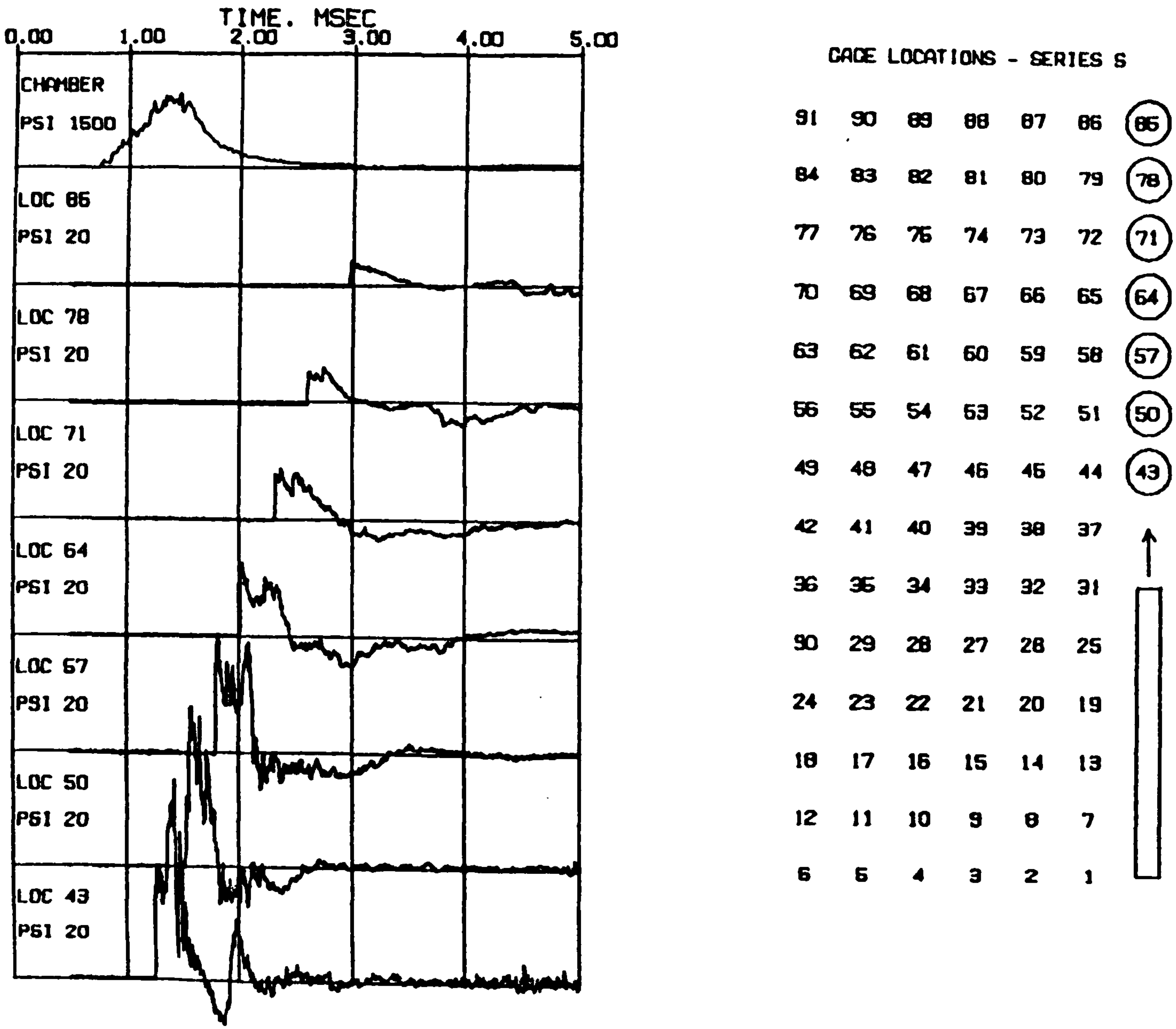

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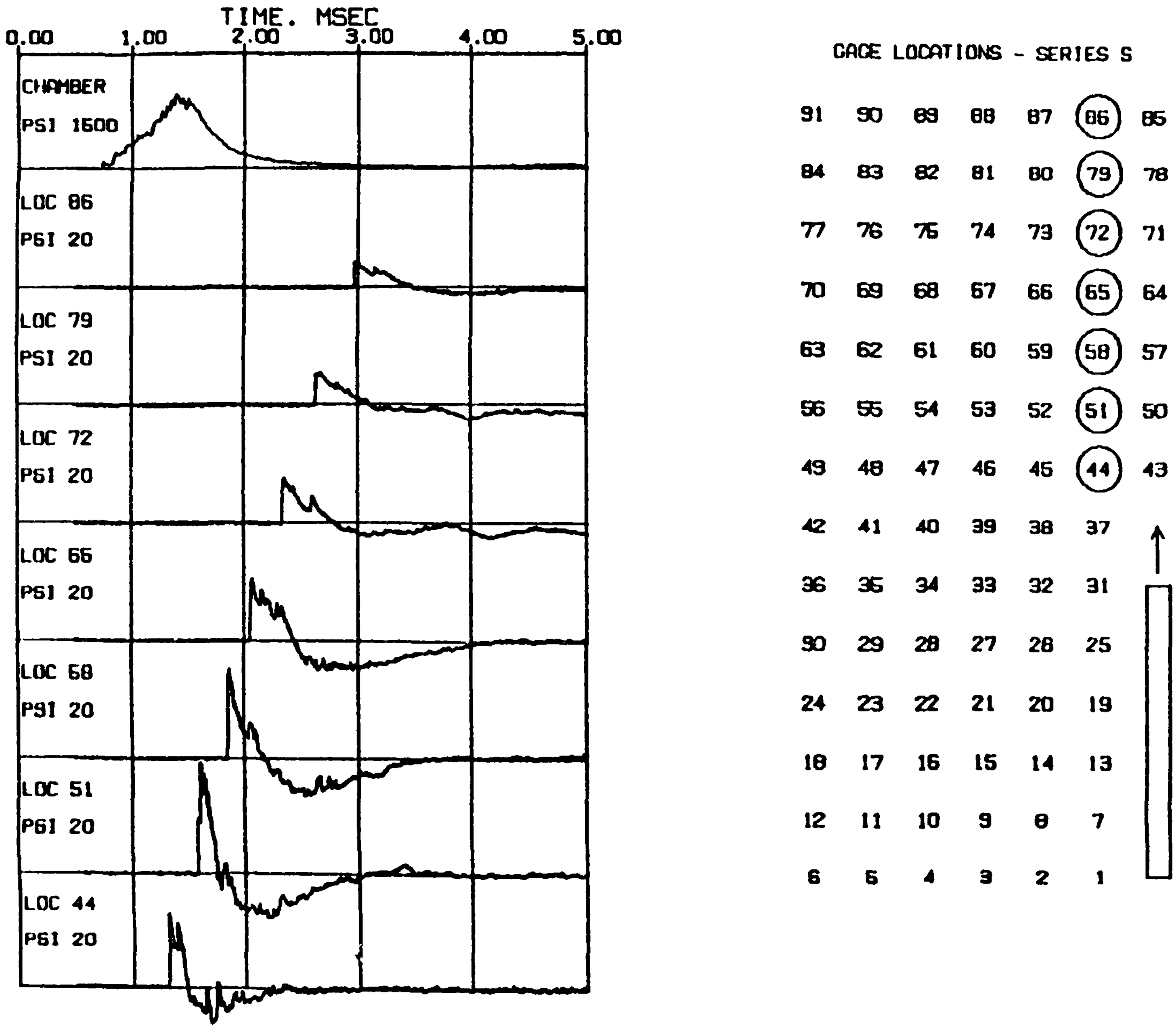

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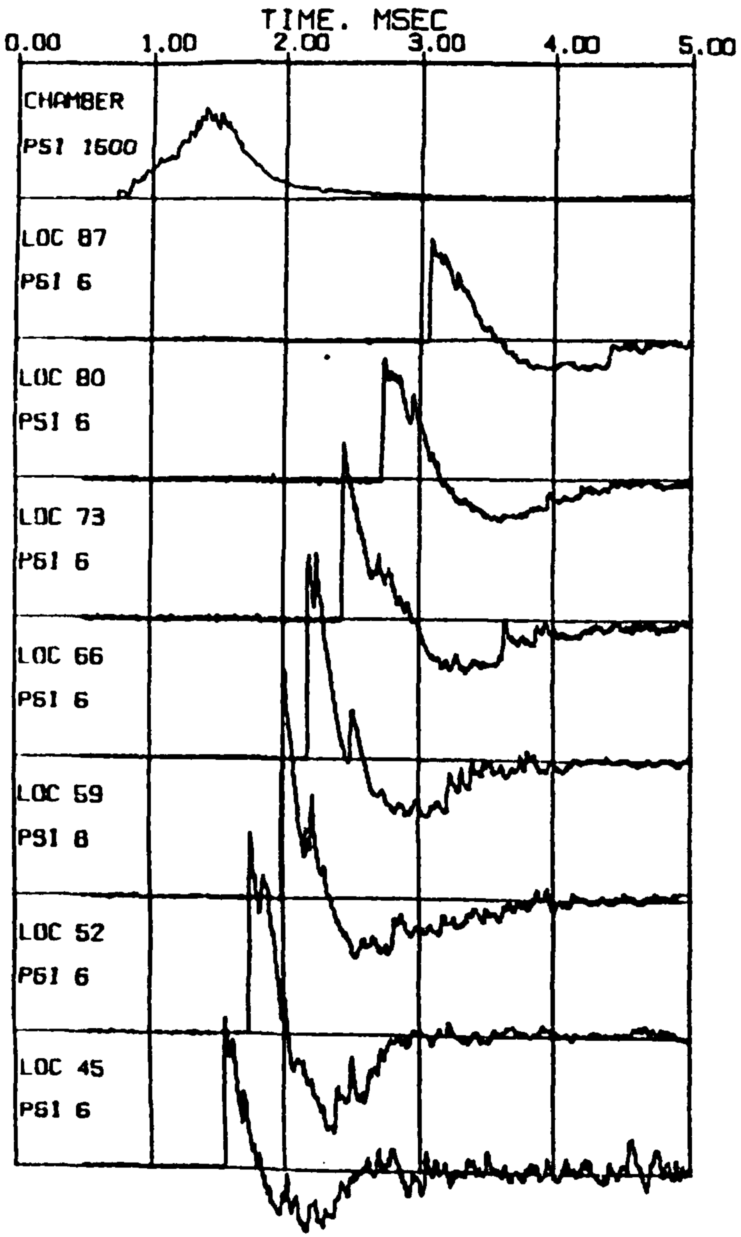

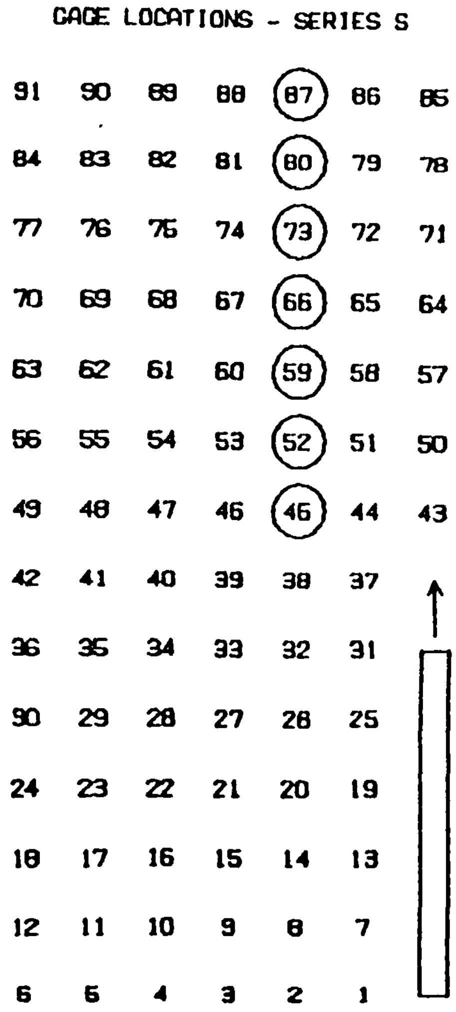

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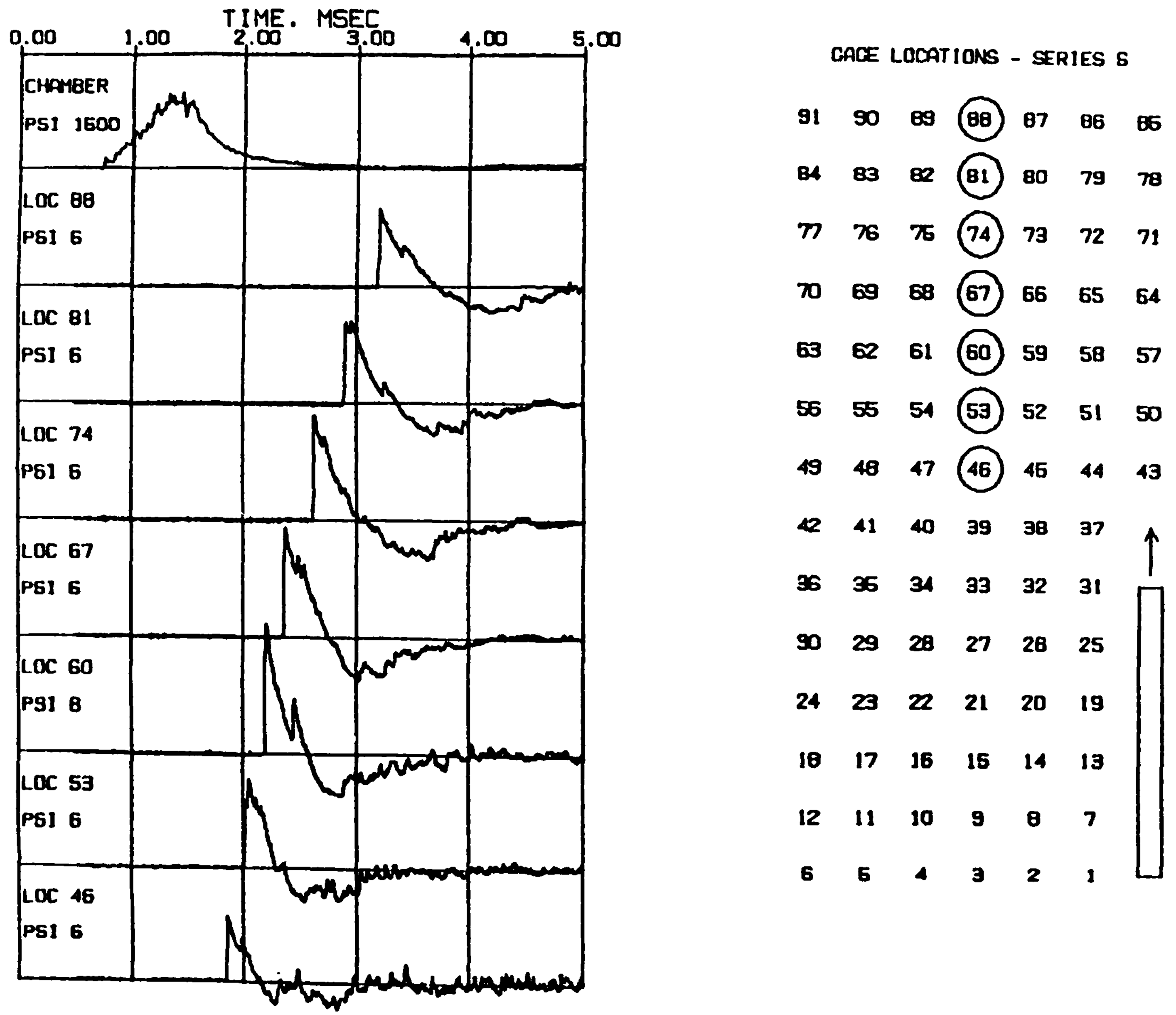

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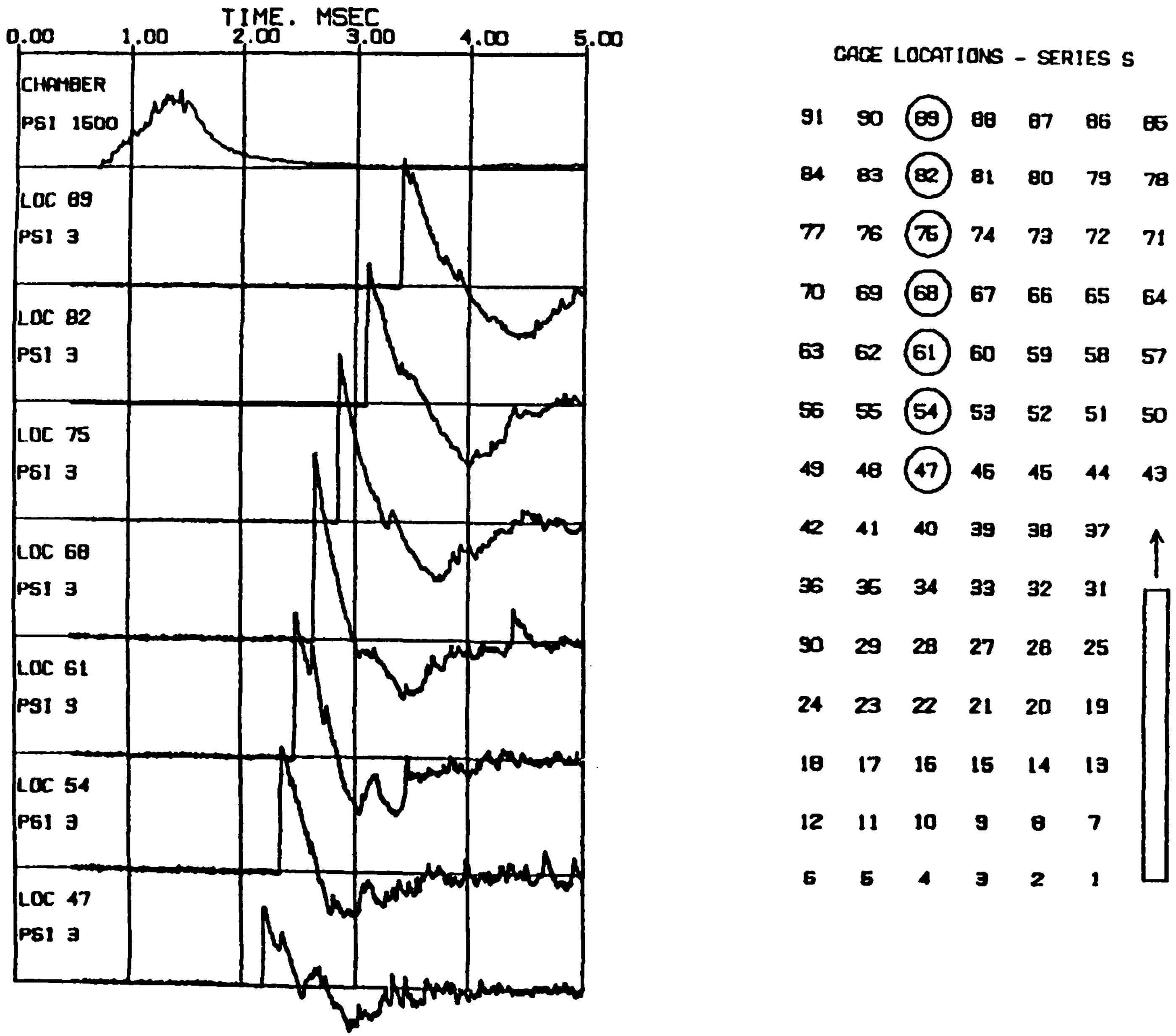

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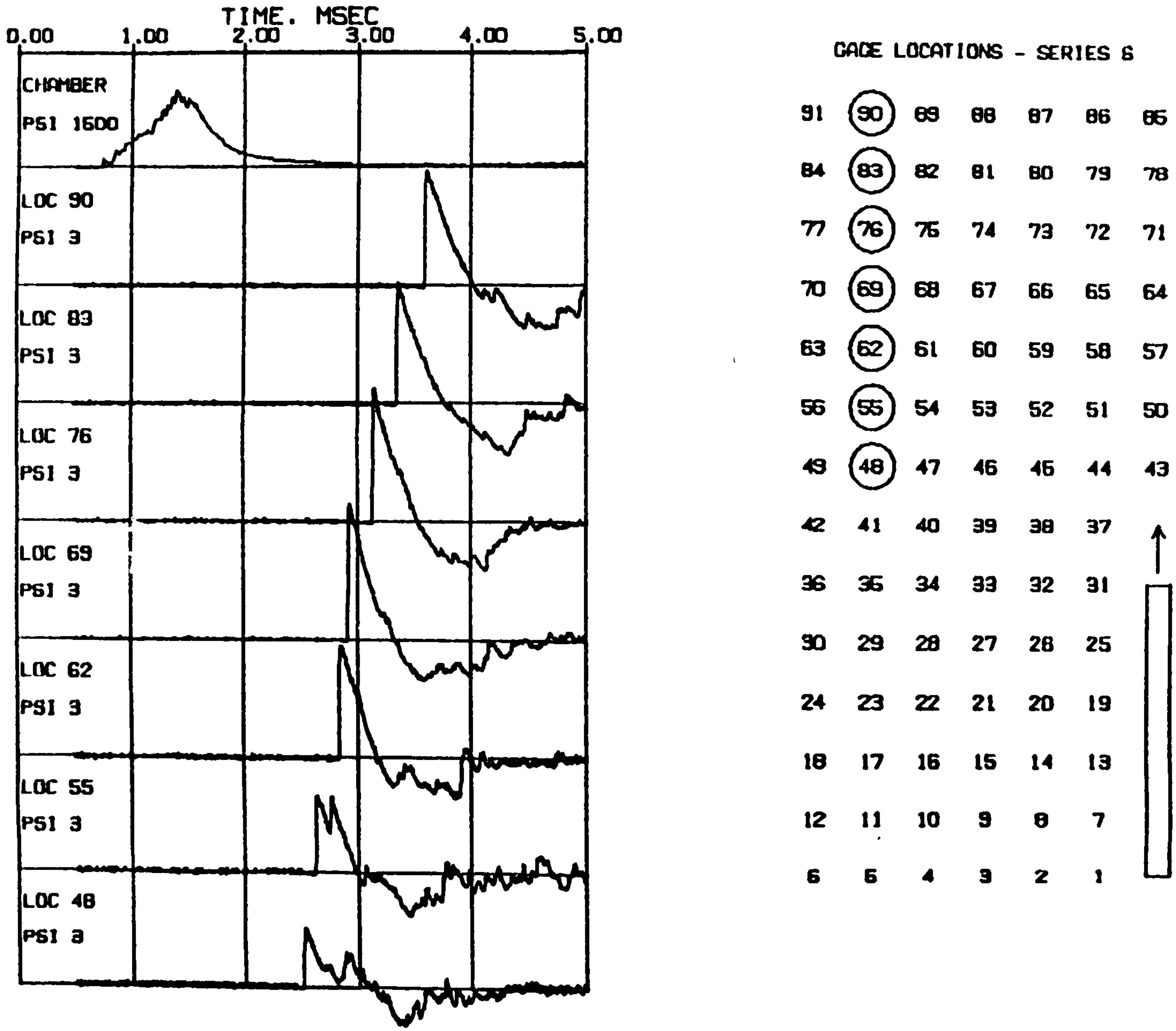

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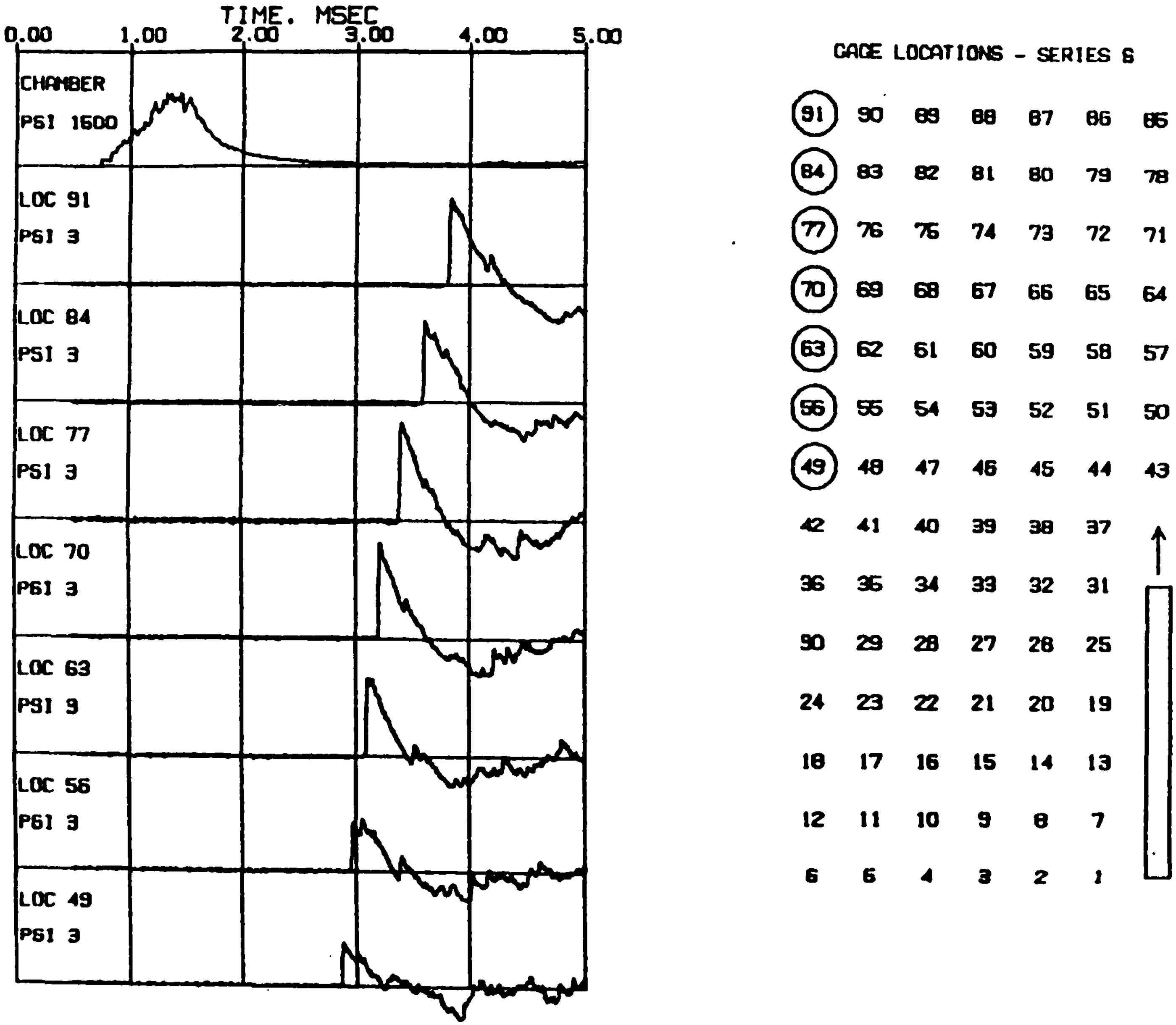

. Figure A13. Experimental Pressure Traces.

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